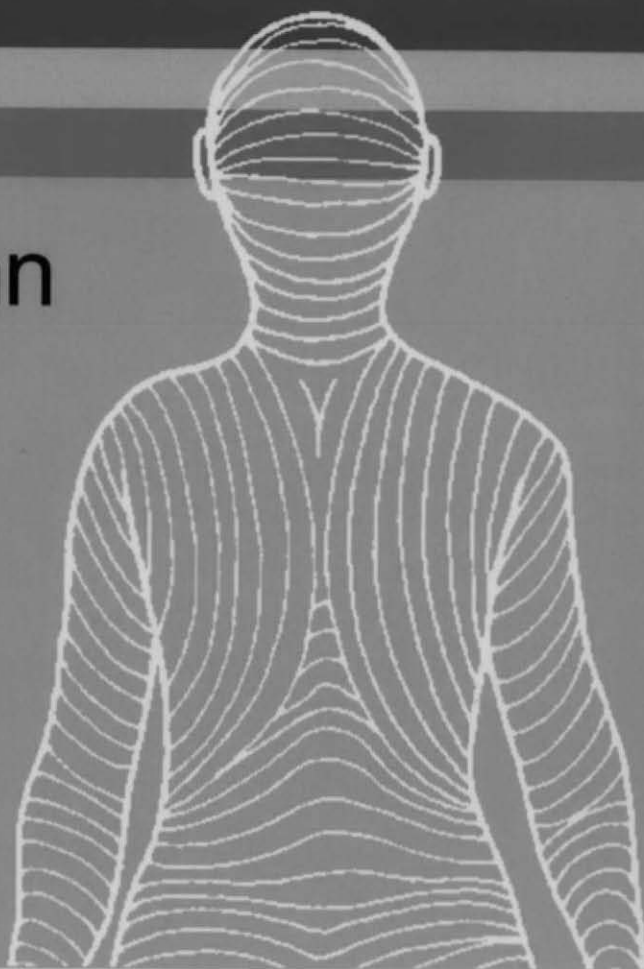


LAST'S ANATOMY

NINTH
EDITION

REGIONAL AND APPLIED

R.M.H. McMinn



Churchill Livingstone

Last's Anatomy
Regional and Applied

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Regional and Applied

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NINTH EDITION



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Medical knowledge is constantly changing. As new information becomes available, changes in treatment, procedures, equipment and the use of drugs become necessary. The authors and the publishers have, as far as it is possible, taken care to ensure that the information given in this text is accurate and up to date. However, readers are strongly advised to confirm that the information, especially with regard to drug usage, complies with the latest legislation and standards of practice.

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Preface

It is sad to have to record that Professor Last died on New Year's Day 1993 in his ninetieth year. Thousands of doctors and surgeons throughout the world owe their interest and understanding of anatomy to him as their former teacher. Many were residents in the Nuffield College of the Royal College of Surgeons of England, where he was Warden for over 20 years, and will remember with affection and gratitude his teaching and the way he always had students' interests at heart.

For this edition there has been extensive revision in many areas, with many additions on the clinical and applied aspects of the subject, and innumerable textual changes throughout in the interests of clarity and accuracy. I am grateful to readers who have written with comments; I regret that not everyone put an address on their letters, so I was not able to acknowledge them all. The problem of what to include and what to leave out is one that exercises all authors and editors, and emphasis changes over the years. Students with future interests in orthopaedics may not feel disposed to get too excited about the pontine paramedian reticular formation, nor the budding ophthalmologist with the axis of inversion and eversion of the foot, but both are part of the rich anatomical tapestry of the body whose normal form and function matter to all; we could not see properly or walk properly without them! The aim has been to strike a reasonable balance between generality and speciality. Discussion with

students about possibly deleting such features as some of the introductory items, details of the skull or of muscle attachments, has led to their retention.

It still remains highly relevant to quote from Professor Last's own first preface: 'I sincerely hope that your reading of the following pages may not only prove profitable to you but will stimulate your permanent interest in a fascinating subject, much of which is still not fully understood.'

I purchased one of the first copies of this book as a very junior lecturer. Little did I imagine that I would one day have the privilege of dedicating the ninth edition of Last's Anatomy in its fortieth year of publication to the memory of its founder.

1994

R. M. H. McMin

RAYMOND JACK LAST
1903-1993

MB, BS Adelaide; Lt. Col, RAMC; Hon Surgeon to the Emperor Haile Selassie of Abyssinia; FRCS Eng; Hon FRACS; Hon FChS; Hon FMAA; Professor of Applied Anatomy and Warden of Nuffield College of Surgical Sciences, Royal College of Surgeons of England; Visiting Professor, University of California, Los Angeles.

The first part of the report deals with the general situation of the country. It is a very interesting and informative study of the country's development. The second part of the report deals with the specific details of the country's development. It is a very detailed and thorough study of the country's development. The third part of the report deals with the specific details of the country's development. It is a very detailed and thorough study of the country's development.

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Acknowledgments

For new artwork in this edition I am again indebted to Mr Philip M Ball, MA, MMAA, Chief Medical Artist at Addenbrooke's Hospital, University of Cambridge. Professor Last, who was one of the instigators in founding the Medical Artists Association, was awarded the Honorary Fellowship of the Association in 1992, and at the presentation ceremony Mr Ball, who is now the Association's Secretary, accepted the award on his behalf.

For illustrations used in previous editions I remain indebted not only to Professor Last and Mr Ball but also to Dr D H Tompsett, Miss J Fairfax Whiteside and Dr Frances S Grover. Drawings of museum specimens in the Royal College of Surgeons of England are reproduced by courtesy of the President of the College. (Colour reproductions of these and many other speci-

mens are available in the Editor's atlases: 'A Colour Atlas of Human Anatomy', RMH McMinn, R T Hutchings, J Pegington and P H Abrahams, 3rd edition, 1993; 'A Colour Atlas of Head and Neck Anatomy', 2nd edition 1994, 'A Colour Atlas of Foot and Ankle Anatomy', 1982, 'A Colour Atlas of Applied Anatomy', 1984, and 'The Human Skeleton', 1987, all by R M H McMinn, R T Hutchings and B M Logan; published by Wolfe Publishing/Mosby Year Book Europe Limited).

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1. Introduction to regional anatomy

PART 1

TISSUES AND STRUCTURES

The body is composed of four basic tissues—epithelium, connective tissue, muscle and nerve—and every part of the body that is examined with either the naked eye or the microscope can only be made up of one or more of these four elements. There are of course different kinds of these tissues depending on the differing functional requirements of the various organs and parts of the body, and the details of cell types and intercellular substances are dealt with in texts on histology. This chapter brings together some notes on certain body tissues and structures to form a relevant introduction to regional anatomy.

SKIN

Skin consists of two elements: epithelium and connective tissue. The epithelium of the skin, which is given the special name of **epidermis**, is of the stratified squamous keratinizing variety. The various skin appendages—sebaceous glands, sweat glands, nails and hair—are specialized derivatives of this epidermis, which is ectodermal in origin. The connective tissue part of the skin, which is mesodermal in origin, is the **dermis**, consisting mainly of bundles of collagen fibres together with some elastic tissue, blood vessels, lymphatics and nerve fibres, all embedded in ground substance. When dried the dermis makes greenhide; when tanned it makes leather.

The uppermost layer of the epidermis is the stratum corneum (Fig. 1.1), the cornified or horny layer, consisting of dead cells (keratin) that have lost their nuclei and that are constantly being rubbed off and replaced by cells moving up from deeper layers. In the scalp scaly flakes of the horny layer may be trapped by hairs instead of falling off invisibly, so forming dandruff.

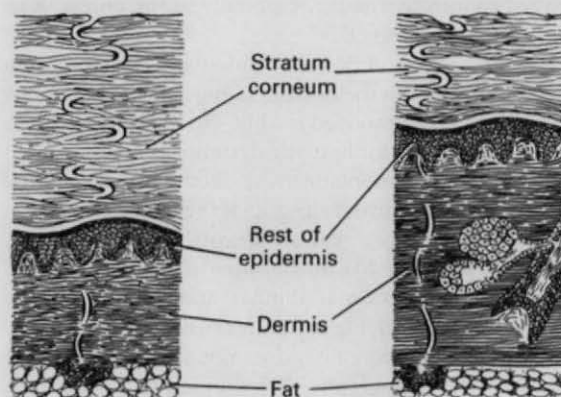


Fig. 1.1 Sections of thick skin, on the left, and thin skin on the right. The definition of thick and thin depends on the thickness of the keratinized layer; the overall depth of the combined epidermis and dermis is the same.

The horny layer is normally softened by the greasy secretion of sebaceous glands and moistened somewhat by the watery secretion of the sweat glands. Fat solvents or emulsifiers remove the grease and leave the horny layer stiff and harsh. Undue contact with water macerates the keratin which, by imbibition, becomes thick, soft and white ('washerwoman's fingers').

The terms thick skin and thin skin refer to the thickness of the cornified layer (Fig. 1.1). In *thick skin*, such as on the sole of the foot, the stratum corneum is thick and paradoxically the dermis is relatively thin. In *thin skin* such as on the front of the forearm the stratum corneum is thin but the dermis relatively thick.

While partly due to its thickness and blood flow, the main factor determining the colour of skin is the degree of pigmentation produced by melanocytes which are mainly found in the basal layer of the epidermis. These cells manufacture melanin granules which are liberated from the melanocytes and ingested by other epidermal cells; thus the presence of melanin granules within a cell does not necessarily imply that the cell has

manufactured them. The synthesizing cells can be distinguished from the others by the dopa reaction, in which Dihydroxyphenylalanine is converted by the enzyme tyrosinase into melanin. The differences in skin colour between the light- and dark-skinned races are not due to differences in melanocyte numbers, for these are similar in all; in the darker skins the melanocytes are more active and thus produce more pigment, but there are also racial differences between melanins which can vary in colour from yellows to browns and blacks. White skin becomes tanned by the sun because ultraviolet light stimulates melanocyte activity (and may also induce cancerous change, especially in the fairest skins that become sunburnt).

The skin is bound down to underlying structures to a variable extent. On the dorsum of the hand or foot it can be pinched up and moved readily. On the palm and sole this is impossible, for here the dermis is bound firmly to the underlying aponeurosis, a necessary functional requirement to improve the grip of the hand and foot.

The *creases* in the skin are flexure lines over joints. The skin always folds in the same place. Along these flexure lines the skin is thinner and is bound more firmly to the underlying structures (usually deep fascia). The site of the flexure lines does not always correspond exactly to the topography of the underlying structures. For example, the anterior flexure line for the hip lies below the inguinal ligament; the posterior flexure line is not influenced by the oblique lower border of gluteus maximus and lies horizontally, to make the fold of the buttock.

Skin contains about 3 million **sweat glands**, which are distributed all over the skin except on the margins of the lips, glans penis and tympanic membranes. The greatest concentration is in the thick skin of the palms and soles, and on the face including the forehead. Structurally they resemble coiled test-tubes that extend below the dermis into the subcutaneous tissue, with ducts that are reasonably straight as they pass through the dermis but which pursue a spiral, corkscrew-like course through the epidermis. There are two types of gland—eccrine and apocrine—although the mode of secretion is the same in both. The vast majority are *eccrine glands* whose purpose is to deliver water to the body surface and so assist in temperature regulation, although those on the palms, soles and forehead respond to emotional stress—as is well known to students in oral examinations! The *apocrine glands* are larger and confined to the axillae, areolae of the breasts and urogenital regions (breasts themselves are modified apocrine glands). They correspond to the scent glands of animals where they are important for recognition in the breeding season, and even in humans they are

under the control of sex hormones, becoming active at puberty. Their ducts, like those of sebaceous glands (see below), open into hair follicles. Although human apocrine secretion is odourless, it may make its presence felt because of the action of skin surface bacteria which degrade it into less appreciated by-products.

Sebaceous glands are usually confined to hairy skin where they open by a very short duct into the side of a hair follicle; only in a few sites do they open directly on to the skin surface—eyelids, lips, papillae of the breasts and labia minora. There are none on the palms or soles. Structurally the glands form a grape-like cluster beside a hair follicle.

Hair: the keratin of the skin surface is soft keratin, but hair and nails are a hard type of keratin. There is no new development of hair follicles after birth. Each hair is formed from the hair matrix, a region of epidermal cells at the base of the hair follicle. As the cells move up inside the tubular epidermal sheath of the follicle they soon lose their nuclei and become converted into the hard keratin rod that is the hair. Melanocytes in the hair matrix impart pigment to the hair cells. The differing colours of hair are due to a mixture of three kinds of pigment. The change with age is due to decreasing melanocyte activity. Most follicles have an arrector pili muscle attached to the connective tissue of the base of the follicle and passing obliquely to the upper part of the dermis. Composed of smooth muscle with a sympathetic innervation, it is on the same side of the follicle as the sebaceous gland, so that when contracting to make the hair 'stand on end', it may also squeeze the gland.

Hair follicles do not grow continually, and growth periods vary in different sites. Those on the scalp have a growing phase of 2–3 years followed by a few months in a resting phase, during which time the hair becomes detached from the base of the follicle and falls out before the matrix starts to make a new hair. Adjacent follicles are out of phase with one another so that the constant renewal and replacement are not obvious. In the eyebrows the growing phase is only a month or two, with a longer resting period.

Nails: a finger- or toe-nail is formed from a nail matrix, a similar epidermal specialization to hair matrices.

Surface area: in skin damage by burns, an estimate of the affected surface area is important in assessing the need for fluid replacement therapy, and the 'Rule of Nines' gives a guide to the size of body parts in proportion to the whole: head 9%; upper limb 9%; lower limb 18%; front of thorax and abdomen 18%; back of thorax and abdomen 18%.

Tension lines and wrinkle lines of skin, due to the pattern of fibre bundles in the dermis, run as indicated

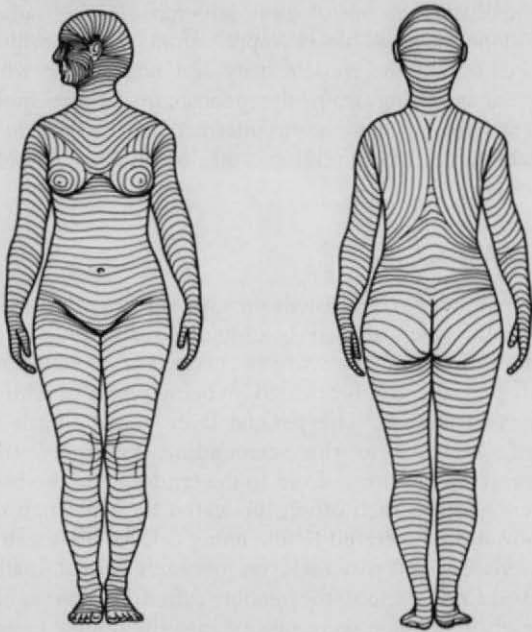


Fig. 1.2 Tension lines of the skin, front and back.

in Figure 1.2. Skin creases such as those near joints run parallel with tension lines, but they and the wrinkles of ageing do not necessarily correspond to the cleavage lines originally described by Langer in 1861. Incisions made along creases and wrinkle lines heal with a minimum of scarring; hence incisions should preferably not be made across these lines, and certainly never across the flexure creases on the flexor surfaces of joints.

SUBCUTANEOUS TISSUE

The skin is connected to the underlying bones or deep fascia by a layer of **areolar tissue** that varies widely in character in different species. In hairy mammals it is loose and tenuous with a minimum of fat, so that it is a simple matter to skin the animal. In others, including man, fat is plentiful and fibrous bands in the fat tether the skin to the deep fascia. Such an animal is more difficult to skin; it has a blanket of fat beneath the skin, called the *panniculus adiposus*. The panniculus adiposus is well developed in man, and in it nerves, blood vessels and lymphatics pass to the skin. The panniculus adiposus is a substitute for a fur coat in 'hairless' mammals (e.g. man, pig, cetacea).

The term *superficial fascia* is so ingrained in nomenclature that there is no hope of discarding it. Yet the tissue bears no possible resemblance to the other so-

called 'deep' fasciae, and the names *panniculus adiposus*, subcutaneous tissue or subcutaneous fat are greatly to be preferred.

In the *panniculus adiposus* are flat sheets of muscle, the *panniculus carnosus*. The degree of their development varies widely in different animals. In domestic quadrupeds such as sheep and horses the sheet is present over most of the body wall. It can be seen on the carcass in a butcher's shop, lying on the surface of the fat, generally incised in parallel slits to make an attractive pattern. It can be seen in action when a horse twitches the skin over its withers. The essential point about the *panniculus carnosus* is that one end of each muscle fibre is attached to the skin, the other end being usually attached to deep fascia or bone.

In man the sheet is well developed and highly differentiated to form the muscles of the scalp and face including the platysma, and remnants persist in such subcutaneous muscles as the palmaris brevis and as unstriped muscle in the corrugator cutis ani, in the dartos sheet of the scrotum and in the subareolar muscle of the nipple.

DEEP FASCIA

The limbs and body wall are wrapped in a membrane of fibrous tissue, the **deep fascia**. It varies widely in thickness. In the iliotibial tract of the fascia lata, for example, it is very well developed, while over the rectus sheath and external oblique aponeurosis of the abdominal wall it is so thin as to be scarcely demonstrable and is usually considered to be absent. In other parts, such as the face and the ischioanal fossa, it is entirely absent. A feature of the deep fascia of the body and limbs is that it never passes freely over bone but is always anchored firmly to the periosteum. A pin thrust into a muscle will pass through skin, subcutaneous tissue and deep fascia; one thrust into a subcutaneous bone will pass through skin, *panniculus adiposus* and periosteum only (Fig. 1.3).

The deep fascia serves for attachment of the skin by way of fibrous strands in the subcutaneous tissue. In a few places it gives attachment to underlying muscles, but almost everywhere in the body the muscles are free to glide beneath it as they lengthen and shorten.

Deep fascia is very sensitive. Its *nerve supply*, and that of subcutaneous periosteum where no deep fascia exists, is that of the overlying skin. The nerves to muscles do not supply the investing layer of deep fascia, but only the fibrous tissue of deep intermuscular spaces, and deep periosteum.

As well as the investing layer of deep fascia on the surface of the body there are many other fascial layers in deeper parts, of widely differing character. In general it

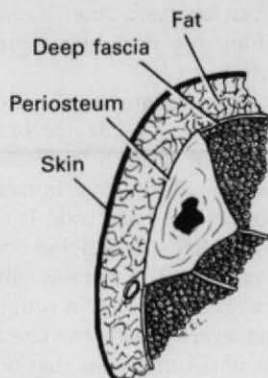


Fig. 1.3 Deep fascia blending with periosteum in a transverse section of the tibia.

may be said that where fasciae lie over non-expansile parts (e.g. muscles of the pelvic wall, prevertebral muscles) they are well developed membranes readily demonstrable, able to be sutured after incision; but where they lie over expansile parts (e.g. muscles of the pelvic floor, cheek, pharynx) they are indefinite and thin collections of loose areolar tissue, nothing more nor less than the epimysium of the underlying muscle (p. 5).

LIGAMENTS

Ligaments are composed of dense connective tissue, mainly collagen fibres (white fibrous tissue) and they attach bone to bone. They have the physical property of being non-elastic and unstretchable. Only if subjected to prolonged strain will collagen fibres elongate, and undue mobility is then possible in the joints (e.g. in flat feet, contortionists). White fibrous tissue ligaments are so arranged that they are never subjected to prolonged strain, with the curious exception of the sacroiliac ligaments and the intervertebral discs, which are never free from the strain of the whole weight of the body except in recumbency.

A second type of ligament is composed of elastic tissue, which regains its former length after stretching. It is yellow in colour, hence the name of the *ligamenta flava* between the laminae of the vertebrae. The capsular ligaments of the joints of the auditory ossicles are made of yellow elastic tissue.

TENDONS

Tendons have a similar structure to collagenous ligaments, and attach muscle to bone. They may be cylindrical or flat; even if flattened into sheet-like

aponeuroses the histological structure is the same. Tendons have a blood supply from vessels which descend from the muscle belly and anastomose with vessels ascending from the periosteum at the bony attachment. In long tendons intermediate vessels from a neighbouring artery reinforce the longitudinal anastomosis.

Synovial sheaths

Where tendons bear heavily on adjacent structures, and especially where they pass around loops or pulleys of fibrous tissue or bone which change the direction of their pull, they are lubricated by being provided with a **synovial sheath**. The parietal layer of the sheath is firmly attached to the surrounding structures, the visceral layer is firmly fixed to the tendon, and the two layers glide on each other, lubricated by a thin film of synovial fluid secreted by the lining cells of the sheath. The visceral and parietal layers join each other. Usually they do not enclose the tendon cylindrically; it is as though the tendon were pushed into the double layers of the closed sheath from one side (Fig. 1.4). In this way blood vessels can enter the tendon to reinforce the longitudinal anastomosis. In other cases blood vessels perforate the sheath and raise up a synovial fold like a little mesentery—a mesotendon or vinculum—as in the flexor tendons of the digits (Fig. 2.54C, p. 118).

RAPHES

A **raphe** is an interdigitation of the short tendinous ends of fibres of flat muscle sheets. It can be elongated passively by separation of its attached ends. There is, for example, no such structure as a *pterygomandibular ligament*; if there were, the mandible would be fixed, since ligaments do not stretch. The buccinator and superior constrictor interdigitate in the *pterygomandibular raphe*, the length of which varies with the position of the mandible. The mylohyoid raphe, pharyngeal raphe and anococcygeal raphe are further examples.

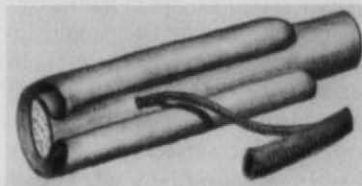


Fig. 1.4 Arterial supply to a long tendon, with the vessel passing through a gap in the synovial sheath.

CARTILAGE

Cartilage is a type of dense connective tissue in which cells and fibres are embedded in a firm ground substance or matrix, and there are three types. The commonest is **hyaline cartilage**, which covers the articular surfaces of typical synovial joints and forms the epiphyseal growth plates of growing bones. The usual histological sections of cartilage give no idea of the amount of collagen fibres that it contains, because the fibres and ground substance both have the same refractive index. Unlike bone, cartilage is avascular and capable of a small amount of deformation; it therefore has a certain resistance to fracture, but when it is damaged it is usually repaired by the formation of fibrous tissue, not new cartilage. However, there are circumstances in which new cartilage can develop, not from surviving cartilage cells but by the differentiation of 'osteochondrogenic' cells—the name sometimes now given to cells of the osteogenic layer of the periosteum which appear capable of becoming osteoblasts or chondroblasts depending on the vascularity of the area (p. 9).

Fibrocartilage resembles ligament and tendon but contains small islands of cartilage cells and ground substance between the collagen bundles. It is found in intervertebral discs and the discs or disc-like structures of some joints, such as the labrum of the shoulder and hip joints and the menisci of the knee joint. It also occurs on the articular surfaces of the clavicle and mandible, and at those attachment sites of tendon to bone epiphyses, which leave a smooth marking on the bone. Both hyaline cartilage and fibrocartilage tend to calcify and even ossify in old age.

The third type, **elastic cartilage** (epiglottis and pinna), has a ground substance that contains large numbers of elastic fibres. It can be easily distorted, and just as easily springs back to its original shape when at rest. It is functionally ideal for the skeletal framework of the human pinna, the auditory tube and the epiglottis. It never calcifies or ossifies.

Fibrocartilage has an ordinary blood supply (rather sparse because its metabolic rate is low) but hyaline and elastic cartilage have no capillaries, their cells being nourished by diffusion through the ground substance.

MUSCLE

There are three kinds of **muscle**—skeletal, cardiac and visceral—although the basic histological classification is into two types—*striated* and *non-striated*. This is because both skeletal and cardiac muscle are striated, a structural characteristic due to the way the filaments of

actin and myosin are arranged. The term *striated muscle* is usually taken to mean skeletal muscle. Visceral muscle is non-striated and so is usually called smooth muscle (although it too contains filaments of actin and myosin, but they are arranged differently). The terms 'muscle cell' and 'muscle fibre' are the same thing. Smooth and cardiac muscle fibres, like most cells, usually have a single nucleus, but skeletal muscle fibres are multinucleated cells; in fibres that are several centimetres long there are thousands of nuclei, characteristically situated just beneath the cell membrane.

Smooth muscle consists of narrow spindle-shaped cells usually lying parallel. In tubes that undergo peristalsis they are arranged in longitudinal and circular fashion (as in the alimentary canal and ureter). In viscera that undergo a mass contraction without peristalsis (such as urinary bladder and uterus) the fibres are arranged in whorls and spirals rather than demonstrable layers. Contractile impulses are transmitted from one cell to another at sites called *nexuses* or *gap junctions*, where adjacent cell membranes lie unusually close together. Innervation is by autonomic nerves and because of the gap junctions many muscle fibres do not receive nerve fibres.

Cardiac muscle consists of much broader, shorter cells that branch. Part of the boundary membranes of adjacent cells make very elaborate interdigitations with one another (at the 'intercalated discs' of light microscopy) to increase the surface area for impulse conduction. The cells are arranged in whorls and spirals; each chamber of the heart empties by mass contraction, not peristalsis. Innervation, like that of visceral muscle, is by autonomic nerves.

Skeletal muscle (the red meat of the butcher) consists of non-branching fibres bound together by loose areolar tissue containing the usual complement of cells such as fibroblasts and macrophages. This connective tissue is condensed like the skin of a sausage on the surface of all muscles, forming a membrane of varying thickness and density well known to every dissector; it is the material dissected away and discarded in the process of 'cleaning' a muscle for demonstration purposes. The membranous envelope, or *epimysium*, is impervious to the spread of fluid such as pus. It is seldom of such a nature as to warrant special description as a named fascia, but one such in the neck is the buccopharyngeal fascia (p. 488).

Skeletal muscle fibres can be shown by histochemical and other means to be of two types, often called red and white, and, while in animals there are some whole skeletal muscles which consist of a single type, all human muscles are a mixture of both types and all appear red, although one type may predominate. The

red fibres, slow twitch in physiological terms with aerobic respiration, have a high content of mitochondria, myoglobin, succinic dehydrogenase and other oxidative enzymes, and low myosin ATPase. *White fibres*, fast twitch and anaerobic, are characterized by the reverse of the above features and have a high glycogen and phosphorylase content. The fibres of a single motor unit (the fibres supplied by the branches of a single neuron) are all of the same type, but if the nerve supply is altered (as by regeneration of nerve fibres after injury) the type becomes altered. In contrast to smooth and cardiac muscle, each individual skeletal muscle fibre receives a motor nerve fibre.

Embedded among the ordinary skeletal muscle cells are groups of up to about 10 small specialized muscle fibres that constitute the **muscle spindles**. The spindle fibres are held together as a group by a connective tissue capsule and hence are called *intrafusal fibres* (lying within a cigar-shaped or fusiform capsule), in contrast to ordinary skeletal muscles fibres which can be called *extrafusal*. Muscle spindles are constant in position in any given muscle and are most numerous (relative to the muscle bulk) in muscles concerned with fine movements (e.g. 368 in *latissimus dorsi*, 80 in *abductor pollicis brevis*). The intrafusal fibres are innervated by the γ motor neurons of the anterior horn, in contrast to ordinary (*extrafusal*) fibres which receive their motor supply from the large α cells. Spindles act as one type of sensory receptor, transmitting to the central nervous system information on the state of contraction of the muscles in which they lie. The afferent fibres (types Ia and II, p. 17) come from primary (annulospiral) and secondary (flowerspray) endings which wrap themselves round parts of the spindle cells.

SKELETAL MUSCLES

The disposition of the individual fibres in a muscle can be in one of only two ways, namely, parallel or oblique to the line of pull of the whole muscle. In the former maximum range of mobility is assured, in the latter the range of mobility is less but increased force of pull of the muscle is correspondingly gained. A good example of a muscle with parallel fibres is provided by *sartorius*. In flexing the knee and hip and laterally rotating the hip the muscle is contracted to its shortest length; reversing the movements elongates the muscle by 30%. Other examples of muscles with parallel fibres are *rectus abdominis*, the *infrahyoid* group, the *extrinsic eye* muscles, the anterior and posterior fibres of *deltoid*, the flank muscles of the abdomen, and the *intercostals*.

Muscles whose fibres lie oblique to the line of pull of the whole muscle fall into several patterns:

(1) **Unipennate muscles**. The tendon forms along one margin of the muscle and all the fibres slope into one side of the tendon, giving a pattern like a feather split longitudinally. A good example is *flexor pollicis longus*.

(2) **Bipennate muscles**. The tendon forms centrally, usually as a fibrous septum which enlarges distally to form the tendon proper. Muscle fibres slope into the two sides of the central tendon, like an ordinary feather. An example is *rectus femoris* (in which muscle the fibres slope *upwards* towards the central septum).

(3) **Multipennate muscles**. These are of two varieties: a series of bipennate masses lying side by side, as in the acromial fibres of *deltoid*, *subscapularis*, etc.; and a cylindrical muscle within which a central tendon forms. Into the central tendon the sloping fibres of the muscle converge from all sides. An example is the *tibialis anterior*. A further variety, unique, is provided by *soleus*. The main bulk of this powerful muscle consists of short fibres that slope between two aponeuroses, downwards from the deep to the superficial.

In a muscle whose fibres run parallel with its line of pull a given shortening of muscle fibres results in equal shortening of the whole muscle. In unipennate and multipennate muscles a given shortening of muscle fibres results in less shortening of the whole muscle. The loss of shortening is compensated by a corresponding gain in force of pull. Obliquity of pull of a contracting fibre involves a loss of mechanical efficiency. But the *number* of oblique fibres is much greater than the number of longitudinal fibres required to fill the volume of a long muscle belly. The greater number of oblique fibres, though each fibre loses some efficiency, results in an overall gain of power in the muscle as a whole. Such muscles are found where great power and less range of movement are needed.

Surface appearance

Some muscles are wholly fleshy, some largely aponeurotic, while many have a quite characteristic mixture of the two. Such variations provide an illustration of the relation of form to function. If the surface of a muscle bears heavily on an adjacent structure it will be covered by a glistening aponeurosis; where there is no pressure there is usually flesh. Examples are manifold, and in this book the surface appearances of many muscles are described. Here *rectus femoris* may be cited as a good example. The anterior surface of this bipennate muscle is fleshy where it lies beneath the *fascia lata*, being

aponeurotic only at its upper end, where it plays against a fibrofatty pad that separates it from sartorius. Its deep surface is exactly the reverse. At the upper end is flesh, but the remainder of the posterior surface is wholly aponeurotic, where the muscle plays heavily on a corresponding aponeurosis of the anterior surface of vastus intermedius. The advantage of knowing the surface characteristics of muscles should be obvious to both physician and surgeon. For the physician, for example, the diagnosis of 'rheumatic' pain or tenderness will often hinge on whether the site is over aponeurosis or flesh, for where there is an aponeurosis there is a bursa. Such bursae are often very extensive and are usually open at one end, so that effused fluid never distends them, but a 'dry' inflammation comparable to 'dry' pleurisy will produce pain on movement and tenderness on pressure over these aponeuroses. The surgeon sees muscles far more often than bones, and instant recognition of a muscle by its surface appearance gives great confidence and accuracy at operation.

Origins and insertions

There is no reality in these terms, though the sanctity of long usage forces their continued use. 'Attachment' seems the best alternative for both origin and insertion, and is rightly gaining in popularity. The upper attachment is usually the origin and the lower attachment the insertion, but sometimes the lower end is considered the origin (rectus abdominis, popliteus). But which end of a muscle remains fixed and which end moves depends on circumstances and varies with most muscles.

The insertion of a tendon when, as usually, it is near a joint, is almost always into the epiphysis. An exception is the tendon of adductor magnus, the insertion of which into the adductor tubercle is bisected by the epiphyseal line of the femur.

Bone markings

Fleshy origins generally leave no mark on the bone, though often the area is flattened or depressed and thus visible on the dried bone (e.g. pectoralis major on the clavicle). Contrary to usual teaching, insertions of pure tendon, like the attachments of ligaments, almost always leave a *smooth* mark on the bone, though the area may be raised into a plateau or depressed into a fossa (spinati, tibialis anterior, patellar ligament, cruciate ligaments on femur, psoas, obturator tendons on femur, etc.). Rough marks are made where there is an admixture of flesh and tendon, or where there is a lengthy insertion of aponeurosis (e.g. ulnar tuberosity, gluteal crest, linea aspera).

A characteristic of flat muscles that arise from flat bones and play over their surfaces is that the muscle origin does not extend to the edge of the flat bone. The origin of the muscle is set back from the edge of the bone in a curved line. Between the edge of the bone and the curved line is a bare area, over which the contracting muscle slides. This allows a greater range of movement of the contracting muscle fibres. The bare area is invariably occupied by a bursa, and such bursae are always of large size. The bursa may communicate with the nearby joint (e.g. subscapularis, iliatus) in which case infection of one cavity necessarily involves the other. Some of these bursae remain separate from the nearby joint (e.g. supraspinatus, usually infraspinatus, obturator internus). The temporalis muscle is an exception to this rule, for its fibres arise from the whole of the temporal fossa down to the infratemporal crest, and there is no bursa beneath it.

Muscle action

Movements are the result of the co-ordinated activity of many muscles, usually assisted or otherwise by gravity. Bringing the attachments of a muscle (origin and insertion) closer together is what is conventionally described as the 'action' of a muscle (isotonic contraction, shortening it). If this is the desired movement the muscle is said to be acting as a **prime mover**, as when biceps is required to flex the elbow. A muscle producing the opposite of the desired movement—triceps in this example—is acting as an **antagonist**; it is relaxing but in a suitably controlled manner to assist the prime mover. Two other classes of action are described: fixators and synergists. **Fixators** stabilize one attachment of a muscle so that the other end may move, e.g. muscles holding the scapula steady are acting as fixators when deltoid moves the humerus. **Synergists** prevent unwanted movement; the long flexors of the fingers pass across the wrist joint before reaching the fingers, and if finger flexion is the required movement, muscles such as flexor and extensor carpi ulnaris act as synergists to stabilize the wrist so that the finger flexors can act on the fingers. A muscle that acts as a prime mover for one activity can of course act as an antagonist, fixator or synergist at other times. Muscles can also contract isometrically, with increase of tension but the length remaining the same. They can be assisted by gravity, and may contract *paradoxically*, as in 'paying out rope', e.g. when biceps (a flexor) controls extension of the elbow. Many muscles can be seen and felt during contraction, and this is the usual way of assessing their activity, but sometimes more specialized tests such as electrical stimulation and electromyography may be required.

Blood supply

Muscles have a rich blood supply. The arteries and veins usually pierce the surface in company with the motor nerve. From the muscle belly vessels pass to supply the adjoining tendon. Lymphatics run back with the arteries to regional lymph nodes.

Nerve supply

Skeletal muscle is supplied by somatic nerves (p. 16) through one or more motor branches which (in spinal nerves) also contain afferent and autonomic fibres. The efferent fibres in spinal nerves are the axons of the large α anterior horn cells of the spinal cord which pass to extrafusal fibres, and of the small γ cells which supply the spindle (intrafusal) fibres (p. 6). The motor nuclei of cranial nerves provide the axons for those skeletal muscles supplied by cranial nerves. The pathways for neuromuscular control are considered on page 623.

The flat muscles of the body wall are perforated by cutaneous nerves on their way to the skin. Such nerves do not necessarily supply the muscles. However, in the limbs it is a fact that whenever a nerve pierces a muscle it supplies that muscle, and the motor branch leaves the nerve proximal to the muscle. As a matter of *morphological* fact, limb nerves do not pierce muscles at all, but pass actually in planes between distinct morphological masses that have fused together. Whenever a nerve pierces a muscle, suspect a morphological pitfall (e.g. coracobrachialis, supinator, sternocleidomastoid).

Note that all muscles in a limb are supplied by branches of the limb plexus, and that flexor muscles derive their nerve supply from anterior divisions and extensor muscles from posterior divisions of the nerves of the plexus (p. 21).

The nerve to a muscle in the body wall or in a limb contains some 40% of *afferent fibres*. These innervate muscle spindles and mediate proprioceptive impulses. They are indispensable to properly co-ordinated muscle contraction.

The nerves supplying the ocular and facial muscles (third, fourth, sixth and seventh cranial nerves) contain no sensory fibres. Proprioceptive impulses are conveyed from the muscles by local branches of the trigeminal nerve. The spinal part of the accessory nerve and the hypoglossal nerve likewise contains no sensory fibres. Proprioceptive impulses are conveyed from sternocleidomastoid by C2 and 3 and from the trapezius by C3 and 4, and from the tongue muscles probably by the lingual nerve (from the trigeminal).

Sensory pathways form an essential background to coordinated voluntary movements. They mediate propri-

oceptive information from the muscle, its tendon, and the capsule and ligaments of the joint being acted upon. These pathways are stimulated in the clinical investigation of tendon reflexes (p. 28).

BONE

Bone is a type of dense connective tissue with cells and fibres embedded in a calcified ground substance commonly called *bone matrix*. For a tissue that seems so dense and hard perhaps one of its most surprising features is its vascularity. The cells of hyaline cartilage, and indeed of other connective tissues, obtain their nutrition by diffusion through the surrounding intercellular substance, but the cells of bone, lying in their calcified matrix through which diffusion is impossible, have been deprived of this facility. A system of minute channels therefore developed in bone matrix so that each osteocyte (bone cell) can still receive nutritive substances. The smallest channels are the *bone canaliculi* which communicate with larger spaces, the *Haversian canals*, containing the blood capillaries from which plasma can diffuse. During bone development the matrix is laid down in concentric layers (*lamellae*) around the capillaries. *Volkman's canals* are channels that usually run at right angles to the Haversian canals and contain anastomosing vessels between Haversian capillaries.

Macroscopically bone exists in two forms, compact and cancellous. **Compact bone** is hard and dense, and resembles ivory, for which it is often substituted in the arts. True ivory is dentine. **Cancellous bone** consists of a spongework of trabeculae, arranged not haphazardly but in a very real pattern best adapted to resist the local strains and stresses. If for any reason there is an alteration in the strain to which cancellous bone is subjected there is a rearrangement of the trabeculae. The moulding of bone results from the resorption of existing bone by phagocytic osteoclasts and the deposition of new bone by osteoblasts; but it is not known how these activities are controlled and co-ordinated. Although adult bone exists in both cancellous and compact forms, there is no microscopic difference between the two.

The marrow cavity in long bones and the interstices of cancellous bone are filled with marrow, red or yellow as the case may be. This marrow apparently has nothing whatever to do with the bone itself, being merely stored there for convenience. At birth all the marrow of all the bones is red, active haemopoiesis going on everywhere. As age advances the red marrow atrophies and is replaced by yellow, fatty marrow, with no power of haemopoiesis. This change begins in the

distal parts of the limbs and gradually progresses proximally. By young adult life there is little red marrow remaining in the limb bones, and that only in their cancellous ends; ribs, sternum, vertebrae and skull bones contain red marrow throughout life.

Periosteum and endosteum

The outer surfaces of bones are covered with a thick layer of fibrous tissue, in the deeper parts of which the blood vessels run. This layer is the **periosteum** and the nutrition of the underlying bone substance depends on the integrity of its blood vessels. The periosteum is itself osteogenic, its deeper cells differentiating into osteoblasts when required; hence the deeper part is known as the *osteogenic layer*. In the growing individual new bone is laid down under the periosteum, and even after growth has ceased the periosteum retains the power to produce new bone when it is needed, e.g. in the repair of fractures. The periosteum is united to the underlying bone by Sharpey's fibres, particularly strongly over the attachments of tendons and ligaments. Periosteum does not, of course, cover the articulating surfaces of the bones in synovial joints; it is reflected from the articular margins, to join the capsule of the joint.

The single-layered **endosteum** that lines inner bone surfaces (marrow cavity and vascular canals) is also osteogenic and contributes to new bone formation. The mass of inflammatory tissue and bone-forming cells at a fracture site constitutes the fracture *callus*, and it is more accurate to refer to osteogenic cells as osteochondrogenic: in a well-vascularized area they are indeed osteogenic and produce new bone, but in areas that become avascular the cells are chondrogenic and form hyaline cartilage. Excessive cartilage formation instead of bone is characteristic of fracture sites that remain mobile.

Nerve supply

Subcutaneous periosteum is supplied by the nerves of the overlying skin. In deeper parts the local nerves, usually the motor branches to nearby muscles, provide the supply. Periosteum in all parts of the body is very sensitive.

Blood supply

In the adult the nutrient artery of the shaft of a long bone usually supplies little more than the bone marrow. The compact bone of the shaft and the cancellous bone of the ends are supplied by branches from the periosteum, especially numerous beneath muscular and

ligamentous attachments. Before union with the shaft an epiphysis is supplied from the *circulus vasculosus* of the joint (p. 12). Veins are numerous and large in the cancellous red marrow bones (e.g. the basivertebral veins) and run with the arteries in Volkmann's canals in compact bone. Lymphatics are present, but scanty; they drain to the regional lymph nodes of the part.

Development

Bone develops by two main processes, intramembranous and endochondral ossification (ossification in membrane and cartilage). In general the bones of the vault of the skull, the face and the clavicle ossify in membrane, while the long bones of the skeleton ossify in cartilage.

In **intramembranous ossification**, osteoblasts simply lay down bone in fibrous tissue; there is no cartilage precursor. As well as the bones of the skull vault, face and the clavicle, it should be noted that growth in the thickness of other bones (subperiosteal ossification) is also by intramembranous ossification.

In **endochondral ossification** a pre-existing hyaline cartilage model of the bone is gradually destroyed and replaced by bone (Fig. 1.5). Most bones are formed in this way. It is essential to appreciate that the cartilage is *not converted* into bone; it is destroyed and then *replaced* by bone. During all the years of growth there is constant remodelling with destruction (by osteoclasts) and replacement (by osteoblasts), whether the original development was intramembranous or endochondral. Similarly endochondral ossification, subperiosteal ossification and remodelling occurs in the callus of fracture sites (see above).

The site where bone first forms is the *primary centre* of ossification, and in long bones is in the middle of the

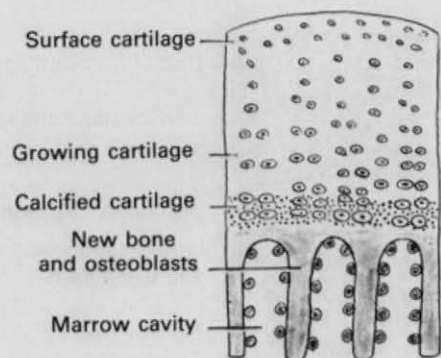


Fig. 1.5 Endochondral ossification in the epiphysis at the end of a long bone.

shaft (*diaphysis*), the centre first appearing about the eighth week of intrauterine life. The ends of the bone (*epiphyses*) remain cartilaginous and only acquire ossification centres much later, usually after birth. The dates of commencement of ossification in epiphyses (secondary centres of ossification) and of their fusion with the diaphysis were much loved of the older anatomists (and examiners). Although students are no longer required to memorize long lists of dates, which in any case are rather variable, it is still important in radiographs of the young and adolescent to be able to recognize the sites of epiphyseal lines (where an epiphyseal plate of cartilage remains between epiphysis and diaphysis) in order to distinguish them from fracture lines.

Secondary cartilage

This is the name given to a special type of cartilage that develops in certain growing membrane bones (head of the mandible and the ends of the clavicle). Both these bones are primarily ossified in membrane. Their articular surfaces are covered with fibrocartilage, identical with the intra-articular disc in structure. Between the bundles of fibrous tissue are many cells. At some distance beneath the articular surface the cells divide, enlarge, and come to lie close together in a groundwork of cartilage that contains many fibres. This 'secondary cartilage' differs in appearance from hyaline cartilage in that its cells are larger and more tightly packed and the matrix is much more fibrous (Fig. 1.6). The secondary cartilage in the neck of the mandible persists until growth of the mandible is complete. It is rather like the epiphysis at the end of a long bone, but unlike the epiphysis it has no secondary centre of ossification.

Note that secondary cartilage has nothing to do with the production of secondary cartilaginous joints

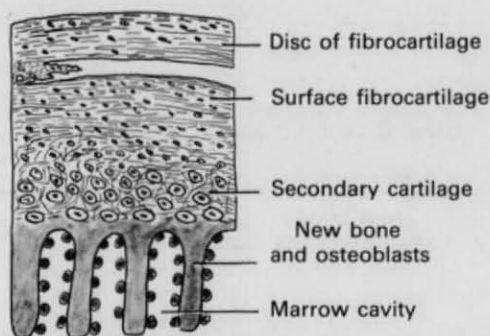


Fig. 1.6 Ossification in secondary cartilage, as in the head of the mandible.

(see below). It provides a cartilage surface for membrane bones that would otherwise have no cartilaginous ends.

Sesamoid bones

Sesamoid bones (meaning seed-like) are usually associated with certain tendons where they glide over an adjacent bone. They may be fibrous, cartilaginous or bony nodules, or a mixture of all three, and their presence is variable. The only constant examples are the patella, which is by far the largest, and the one in each of the two tendons of flexor pollicis brevis in the hand and the foot. Occasional sesamoids in the hand may be found in any of the flexor tendons in front of the metacarpophalangeal joints. In the foot they can occur as in the hand flexor tendons, and other possible sites include the peroneus longus tendon over the cuboid, the tibialis anterior tendon against the medial cuneiform, the tibialis posterior tendon opposite the head of the talus, in any of the tendons at the medial and lateral malleoli, and one in the lateral head of gastrocnemius (where it is known as the fabella, an example not associated with tendon). The reasons for the presence of sesamoids are obscure. Sometimes they appear to be concerned in altering the line of pull of a tendon (patella in the quadriceps tendon) or with helping to prevent friction (as in the peroneus longus tendon moving against the cuboid bone).

JOINTS

Union between bones can be in one of three ways: by fibrous tissue, by cartilage or by synovial joints.

Fibrous joints exist between bones or cartilages. The surfaces are simply joined by fibrous tissue (Fig. 1.7A) and movement is negligible. Fibrous joints unite the bones of the vault of the skull at the sutures; these gradually ossify (from within outwards) as the years pass by. A fibrous joint unites the lower ends of tibia and fibula; this does not ossify.

Cartilaginous joints are of two varieties, primary and secondary. A **primary cartilaginous joint** is one where bone and hyaline cartilage meet (Fig. 1.7B). The junction of bone and cartilage in ossifying hyaline cartilage provides an example. Thus all epiphyses are primary cartilaginous joints, as are the junctions of ribs with their own costal cartilages. All primary cartilaginous joints are quite immobile and are very strong. The adjacent bone may fracture, but the bone-cartilage interface will not separate.

A **secondary cartilaginous joint (symphysis)** is a union between bones whose articular surfaces

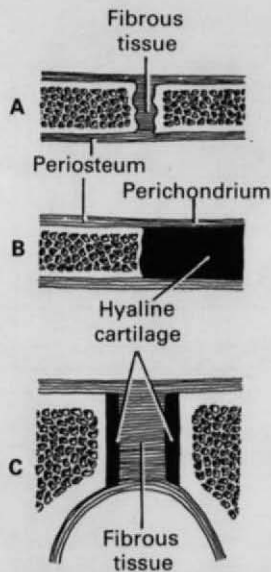


Fig. 1.7 Fibrous and cartilaginous joints in section. **A** Fibrous joint. **B** Primary cartilaginous joint. **C** Secondary cartilaginous joint.

are covered with a thin lamina of hyaline cartilage (Fig. 1.7C). The hyaline laminae are united by fibrocartilage. There is frequently a cavity in the fibrocartilage, but it is never lined with synovial membrane and it contains only tissue fluid. Examples are the pubic symphysis and the joint of the sternal angle (between the manubrium and the body of the sternum). An *intervertebral disc* is part of a secondary cartilaginous joint, but here the cavity in the fibrocartilage contains a gel (p. 537).

A limited amount of movement is possible in secondary cartilaginous joints, depending on the amount of fibrous tissue within them. In spite of the name 'cartilaginous' they have nothing in common with the 'primary' cartilaginous joint.

Fully developed **synovial joints**, which include all limb joints, are characterized by six features: the bone ends taking part are covered by *hyaline cartilage* and surrounded by a *capsule* enclosing a joint cavity, the capsule is reinforced externally or internally or both by *ligaments* and lined internally by *synovial membrane*, and the joint is capable of varying degrees of movement.

The joint capsule is properly called the capsular ligament; do not forget to include it if being questioned about the ligaments of a joint. In the fetus the epiphyseal line gives attachment to the capsule, but this attachment may later wander on to either the epiphysis

or the shaft, causing the adult epiphyseal line to be intracapsular or extracapsular (Fig. 1.8). The synovial membrane lines the capsule and invests all non-articulating surfaces within the joint, i.e. it is attached round the articular margin of each bone. Certain cells of the membrane secrete a hyaluronic acid derivative which is responsible for the viscosity of the fluid, whose main function is lubrication. It has the extraordinary capacity of being able to vary its viscosity, becoming thinner with rapid movement and thicker with slow. However, synovial joints should not be compared with machine bearings which require hydrodynamic lubrication. Under slow-moving weight bearing, hyaline cartilage on joint surfaces possesses an inherent slipperiness greater than that of a skate on ice. Do not imagine that there are large amounts of synovial fluid in joints; in normal joints the fluid is a mere film. The largest joint of all, the knee, only contains about 0.5 ml, but of course injury or disease may cause large effusions.

The extent to which the cartilage-covered bone-ends make contact with one another varies with different positions of the joint. When the surfaces make the maximum possible amount of contact the joint is said to be *close-packed* (as in the knee joint in full extension); the capsule and its reinforcing ligaments are at their tightest. When the surfaces are less congruent (as in the partly flexed knee), the joint is loose-packed and the capsule looser, at least in part. The varying degrees of

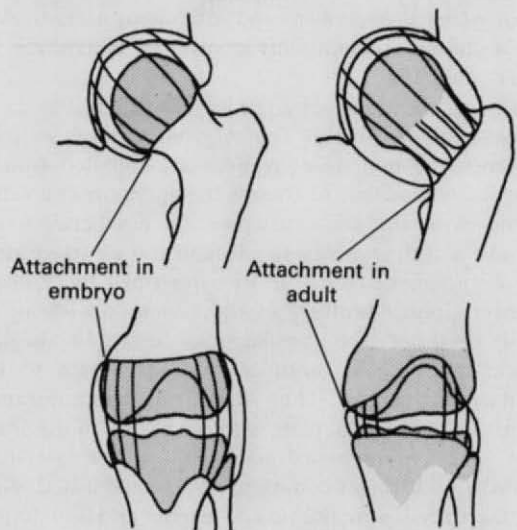


Fig. 1.8 Migration of joint capsules from the epiphyseal line. The epiphysis of the head of the femur becomes intracapsular, while that of the lower end becomes extracapsular.

contact enable the sites of maximal stress to vary, so spreading the load.

Intra-articular fibrocartilages. Discs or menisci of fibrocartilage are found in certain joints, usually but not always in contact with bones that have developed in membrane. They may be complete or incomplete. They occur characteristically in joints in which two separate movements take place, each movement occurring in its own compartment (elevation and depression at the sternoclavicular joint, rotation at the knee).

Fatty pads are found in some synovial joints, occupying spaces where bony surfaces are incongruous. Covered in synovial membrane, they probably function as swabs to spread synovial fluid. Examples occur in the hip (the Haversian fat pad, p. 167) and the talocalcaneonavicular joint (p. 205) and in the infrapatellar fold and alar folds of the knee joint (p. 182).

Blood supply

Hyaline cartilage is bloodless, bone is a bloody structure. As a centre of ossification appears, blood vessels grow in from any convenient artery. The nutrient vessel to the shaft of a long bone branches generally from the main artery of the particular limb segment concerned and, as elongation of the bone proceeds, the artery gets carried obliquely away from the growing end of the bone. The end of the shaft in contact with the epiphyseal plate of cartilage is the *metaphysis*. In the metaphysis the terminal branches of the nutrient artery of the shaft are end arteries, subject to the pathological phenomena of embolism and infarction; osteomyelitis in the child most commonly involves the metaphysis for this reason (Fig. 1.9).

The cartilaginous epiphysis has, like all hyaline cartilage, no blood supply. The synovial membrane, joint mesenchyme and its derivatives are supplied from a vascular plexus that surrounds the epiphysis and sends branches to the joint structures. It lies between the capsule and the synovial membrane at their attachment to the epiphyseal line. It was described by William Hunter (John's brother) as the *circulus vasculosus*. As ossification of the cartilaginous epiphysis begins, branches from the vascular circle penetrate to the ossification centre. They have no communication across the epiphyseal plate with the vessels of the shaft. Not until the epiphyseal plate ossifies, at cessation of growth, are vascular communications established. Now the metaphysis contains no end arteries and is no longer subject to infarction from embolism; osteomyelitis, once common in the child in this region before the days of antibiotics, no longer has any particular site of election in the bone.

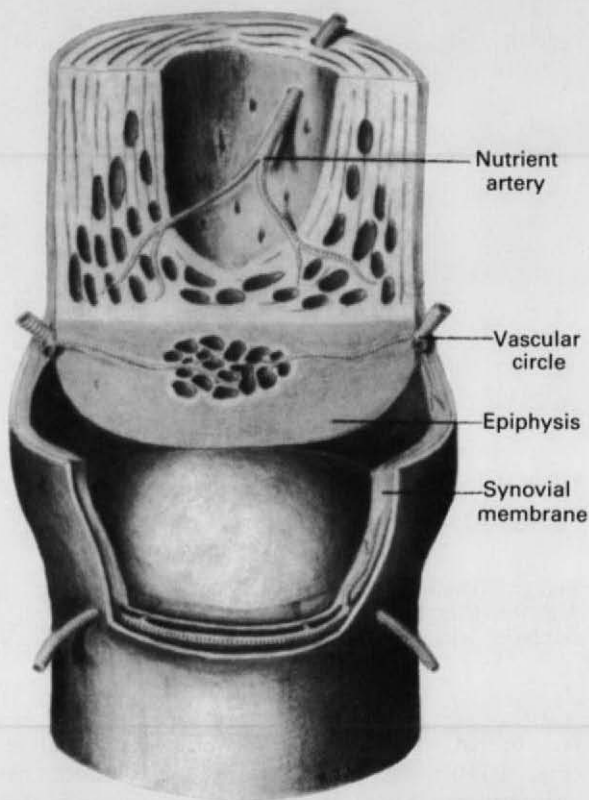


Fig. 1.9 Blood supply of a synovial joint. Part of the capsule is removed and the upper bone is shown in longitudinal section.

Nerve supply

The capsule and other ligaments are supplied by numerous afferent nerve endings, including thinly myelinated pain fibres. Synovial membrane contains relatively few pain fibres, but there are no afferent fibres in articular cartilage; joint pain is poorly localized. *Hilton's Law:* The motor nerve to a muscle tends to give a branch of supply to the joint which the muscle moves and another branch to the skin over the joint.

Stability of joints

Factors contributing to the stability of joints may be conveniently analysed under the headings bony, ligamentous and muscular. Atmospheric pressure is a negligible factor in most joints. The importance of the three factors is nearly always in the ascending order of bone, ligament and muscle.

Bony contours. In such a firm ball and socket joint as the hip, or a mortise joint like the ankle, bony

contours play an important part; but in most joints (e.g. sacroiliac, shoulder, knee, mandibular, arches of foot) they contribute nothing at all to stability.

Ligaments. Ligaments are an important factor in most joints, acting for the most part in preventing over-movement and in guarding against sudden accidental stresses. However, they are usually of no avail in guarding against continuous stress (e.g. in supporting the arches of the foot), since they are composed of white fibrous tissue (collagen) which, once stretched, tends to remain elongated. This is well seen in 'double-jointed' contortionists, in whom the usually restricting ligaments are kept permanently elongated by practice. Elastic tissue in ligaments gives a different picture, since such ligaments shorten after elongation. The ligamenta flava and the ligaments of the joints of the auditory ossicles are composed of yellow elastic tissue, an important factor in maintaining stability of the joints concerned. Yellow elastic fibres compose the nuchal ligament of long-necked animals, but not of man, whose skull is balanced on the vertical cervical spine and whose nuchal ligament consists merely of a thin sheet of fibrous tissue, a median intermuscular septum.

Muscles. In almost all joints muscles are the most important, and in many an indispensable factor in maintaining stability. Such joints as the knee and shoulder are very unstable without their muscles; wasting of vastus medialis after synovial effusion, for example, is followed by a feeling of insecurity in the knee in a matter of hours. The short muscles of the scapula are indispensable as fixators of the shoulder joint in all movements of the upper limb. Muscles are essential to the maintenance of the arches of the foot. There are many other examples. The matter of stability is discussed under individual joints.

MUCOUS MEMBRANES

A **mucous membrane** is the lining of an internal body surface that communicates with the exterior. This definition must not be taken to imply that all mucous membranes secrete mucus; many parts of the alimentary and respiratory tracts do but most of the urinary tract does not. Mucous membranes consist of two and sometimes three elements: always an *epithelium* and an underlying connective tissue layer, the *lamina propria*, which in much of the alimentary tract contains a thin third component of smooth muscle, the *muscularis mucosae*. The whole mucous membrane, often called 'mucosa', usually lies on a further connective tissue layer, the submucous layer or submucosa. The epithelium of a mucous membrane varies according to the site

and functional needs, e.g. stratified squamous in the mouth, columnar in the intestine, ciliated in the trachea.

SEROUS MEMBRANES

A **serous membrane** (serosa) is the lining of a closed body cavity — pericardial, pleural and peritoneal — and consists of connective tissue covered on the surface by a single layer of flattened mesothelial cells (derived from the mesoderm of the coelomic cavity). The part of the serosa that lines the wall of the cavity (the parietal layer of pericardium, pleura or peritoneum) is directly continuous with the same membrane that covers or envelops the mobile viscera within the cavity (the visceral layer). The peritoneal, pericardial and pleural cavities are thus potential slit-like spaces between the *visceral layer* that clothes the viscus and the *parietal layer* that lines the walls of the cavity. The two layers slide readily on each other, lubricated by a film of tissue fluid (lymph). There are no glands to produce a lubricating secretion. The serous membranes are usually very adherent to the viscera, from which they can be stripped only with some difficulty. The parietal layer is attached to the wall of the containing cavity by loose areolar tissue and in most places can be stripped away easily. The word 'serosa' is a diminutive of 'serous membrane'. Although the female peritoneal cavity theoretically communicates with the exterior via the uterine tubes, uterus and vagina, it must still be classified with its male counterpart as having a serous lining.

Nerve supply

The parietal layer of all serous membranes is derived from the somatopleure, and is supplied segmentally by spinal nerves. The visceral layer, developed from the splanchnopleure, possesses no sensory supply (p. 36).

BLOOD VESSELS AND LYMPHATICS

Perhaps more than any other arrangement in the body vascular patterns vary within extremely wide limits. This is not surprising when one thinks for a moment of the way in which the adult pattern is reached. The embryo is little more than a bloody sponge, possessing a vast and intricate network of anastomosing veins. Arteries are sprouting, new vessels replacing the old, while the venous pattern is reached by the disappearance of most of the network of veins in the embryo. The wonder is that such uniformity of pattern is ever attained. The site of origin of a branch from the parent

trunk is very variable; the field of supply is much less variable (this applies to peripheral nerves, too).

An interesting feature of embryology is found in the fate of the vessels supplying an organ that migrates far from the site of its original appearance. In one case the vessels may persist, merely elongating to reach the organ, as in the gonads; in another case a series of new vessels appear, replacing the old as the organ migrates, as in the kidney. The kidney is developed at the pelvic brim, where it is supplied by the prolongation of the dorsal aorta known as the median sacral artery. As the kidney 'climbs' up the posterior abdominal wall it is supplied successively from the internal iliac and common iliac arteries and then by a series of branches from the abdominal aorta until the definitive adult position is reached. One or more aortic branches may persist as 'abnormal' renal arteries.

It is true of all parts of the body that veins are bigger than their corresponding arteries, for the simple hydrodynamic reason that the rate of flow is so much slower in them. For the same reason they are often double, as the *venae comitantes* of peripheral limb arteries. Note that in both the hand and the foot most of the venous return is by way of the dorsum, to escape the pressure of the palm and sole which would constrict the veins. In the proximal parts of limbs the *venae comitantes* unite into a single large vein (axillary, popliteal).

Large veins have 'dead space' around them, to allow for the great dilatation that takes place during increased blood flow. The axillary vein lies in front of the prevertebral and axillary fasciae where it has adequate room to expand, the femoral vein lies alongside the femoral canal, into which it can readily expand. The internal jugular vein has a loose part of the carotid sheath around it, unlike the dense part over the carotid artery. The pulmonary veins lie in the lower part of the lung root, where they can expand between the two lax layers of the pulmonary ligament. The dead space alongside large veins commonly contains the regional lymph nodes (e.g. deep inguinal nodes alongside the femoral vein, lateral axillary nodes medial to the axillary vein, deep cervical nodes along the internal jugular vein).

Structure

The very smallest vessels, the **capillaries**, consist only of very flattened endothelial cells, but others are made up of three layers of tissue. The *tunica intima* has an endothelial lining with a variable amount of underlying connective tissue which, in **arteries**, includes the internal elastic lamina, giving the characteristic crenated appearance to the lumen of an artery in transverse histological section. The *tunica media* contains

circular smooth muscle fibres, and there is an external elastic lamina at the junction of this and the outer connective tissue layer, the *tunica adventitia*. The largest vessels like the aorta and its branches have a large amount of elastic tissue mixed with the muscle fibres of the *tunica media*. **Veins** have a much thinner *tunica media* than their corresponding arteries, and have no internal elastic lamina. Some vessels have special characteristics. The inferior vena cava has no *tunica media*. In the umbilical arteries the *tunica media* is arranged in two layers, inner longitudinal and outer circular, with no elastic laminae. Because of the thickness of their walls the larger vessels have their own penetrating vessels, the *vasa vasorum*.

Venous valves

Many veins of moderate calibre, both superficial and deep, possess valves whose closure prevents a reversal of bloodflow, especially in the lower limb (the great saphenous vein has about 15). They usually consist of two apposed cusps, rather like miniature cusps of the aortic and pulmonary valves. Their presence in the superficial veins of the arm was a major factor in Harvey's discovery of the circulation of the blood. Among those veins that have no true valves are the superior and inferior *venae cavae*, veins of the head and neck (including the ophthalmic veins and the dural sinuses), vertebral, cardiac, pulmonary, hepatic and pelvic veins, and the portal vein and its tributaries.

Anastomosis of arteries

The anastomoses between various arteries of the body are of great importance in medicine and surgery alike. They are of two types.

(1) **Actual**, where arteries meet end to end. The test for such an anastomosis is that the cut vessel spurts from both ends. Examples are found in the labial branches of the facial arteries, the intercostal arteries, the uterine and ovarian arteries, and the arteries of the greater and lesser curvatures of the stomach, the arterial arcades of the mesentery, the marginal artery of the colon, etc.

(2) **Potential**. Here the anastomosis is by terminal arterioles. Given sufficient time the arterioles can dilate to take sufficient blood, but with sudden occlusion of a main vessel the immediate anastomosis may be inadequate to nourish the part. Examples are seen in the coronary arteries, most of the limb anastomoses in the region of joints, and the cortical arteries of the cerebral hemispheres.

In many cases there is no precapillary anastomosis between adjacent arteries. Such vessels are *end-arteries*, and here interruption of arterial flow necessarily results in gangrene or infarction. Examples are found in the liver, spleen, kidney, lung, medullary branches of central nervous system, the retina and the straight branches of the mesenteric arteries.

Short-circuiting channels (shunts or *arteriovenous anastomoses*) between terminal arterioles and primary venules have been demonstrated in many parts of the body; in fingertips they are complex structures called glomus bodies. They can short-circuit arteriolar blood directly into venules, bypassing the capillary bed, and so causing variations in regional blood flow. In skin they may have a role in temperature regulation, but in general the reasons for their existence and the mechanisms of their control are not understood.

Lymphatic vessels

In considering the blood supply to any organ or part it makes for a more complete picture if arterial input is always linked with venous and lymphatic return. Not all the blood entering a part returns by way of veins; much of it becomes tissue fluid and returns by way of lymphatics.

There is a simple principle that clarifies the whole picture of the lymphatics of the body. It is that *superficial lymphatics* (i.e. in subcutaneous tissues) follow *veins* while *deep lymphatics* follow *arteries*. This is true of almost any part of the body except the tongue, which is quite exceptional. The fact that lymphatics accompany arteries seems to be beneficial, for it is probable that the pulsations of arteries compress the nearby lymphatics and so 'milk' the lymph along. If this is so it would certainly account for the multitude of valves with which lymphatics are provided.

It must be realized that tissue fluid first enters an intricate plexus of minute lymphatic vessels (capillaries) from which there are usually alternative routes to regional lymph nodes. A given drop of lymph may go by one of several paths, depending on local and even distant pressures, and it is only when it reaches a definitive lymphatic vessel with its valves that its subsequent route becomes unalterable. Thus accounts and illustrations of lymphatic drainage vary in different textbooks and atlases. The question, 'Which description is correct?' has no answer, since all may be correct under different circumstances.

Clinical spread of disease (e.g. infection, neoplasm) by lymphatics does not necessarily follow strictly anatomical pathways. Lymph nodes may be bypassed by the disease process. If lymphatics become dilated by

obstruction their valves may be separated and reversal of lymph flow can then occur. Lymphatics communicate with veins freely in many parts of the body; the termination of the thoracic duct may be ligated with impunity, for the lymph finds its way satisfactorily into more peripheral venous channels.

LYMPHOID TISSUE

The defence mechanisms of the body include **phagocytosis**, which is a non-specific engulfing process, and the **immune response** which is a specific reaction to micro-organisms and foreign proteins (antigens). The immune response may occur in two ways: (1) by the *humoral antibody response*, with production of antibodies which are protein molecules that circulate in the blood and attach themselves to the foreign protein so that the combination of antigen and antibody can be destroyed by phagocytosis; and (2) by the *cell-mediated immune response*, with the production of specific cells that circulate in the blood and destroy the antigen or stimulate its phagocytosis. Two types of lymphocyte produce these reactions: *T cells* are responsible for cell-mediated immunity and *B cells* for humoral antibody production. The B cells become transformed into plasma cells which produce the antibody molecules (the various immunoglobulins — IgG, IgM, etc.). This ability to produce large quantities of one particular antibody has led to the development of the 'monoclonal antibody technique' for identifying specific antigens.

All lymphocytes arise from common stem cells in bone marrow (in the embryo, from yolk sac and liver). Some of them circulate to and settle in the thymus where they proliferate. After release into the bloodstream as T cells they colonize the spleen, lymph nodes and other lymphoid follicles by passing through the postcapillary venules of those structures. Other stem cells become B cells and similarly colonize lymphoid follicles. The T cells are so named because they depend on the Thymus for their development; cell-mediated immunity thus depends on this organ. The B cells were not named because they developed from bone marrow, although in man this does happen to be a convenient aid to memory; the name is from the Bursa of Fabricius in birds, for it was in chickens that this organ (near the cloaca) was first found to be the source of humoral antibodies. Although at one time the Peyer's patches of the gut were thought to be the human equivalent of this bursa, bone marrow is currently considered to be the likeliest source. The main types of T cell are at present known as T helper, T suppressor, T killer (cytotoxic) and T memory, while B cells can either form plasma cells or become B memory cells. The discovery of these

various subgroups of lymphocytes and the interactions between themselves and macrophages has made immunology one of the most rapidly developing fields of medical research.

The **lymphoid organs** of human anatomy consist of the thymus, lymph nodes, tonsils and spleen. All have an internal connective tissue framework to support the cellular elements. In all except the thymus the characteristic structural feature is the lymphoid nodule or follicle, which is typically a spherical collection of lymphocytes with a pale central area, the germinal centre (paler than the periphery of the follicle in stained sections because the lymphocytes are more loosely packed centrally). Isolated lymphoid follicles occur in the mucosa and submucosa of all parts of the alimentary and respiratory tracts; collections of follicles in the ileum form the 'aggregated lymphoid follicles' or Peyer's patches. The 'gut associated lymphoid tissue' (GALT) is collectively the largest mass of lymphoid tissue in the body. The special enterocytes (M cells) overlying mucosal lymphoid follicles absorb antigenic material which is then exposed to intraepithelial and follicular lymphocytes and macrophages so that an appropriate immune response can occur.

In the **thymus** the lymphocytes are not concentrated in rounded follicles but form a continuous dense band of tissue at the outer region or cortex of the lobules into which the organ is divided. The inner (paler) regions of the lobules form the medulla which contains the characteristic thymic corpuscles (of Hassall); these are remnants of the epithelium of the third pharyngeal pouches from which the thymus developed. The continuous cortex and the thymic corpuscles immediately identify a typical thymus histologically (although in the ageing adult there is usually much replacement by fibrofatty tissue).

In a typical **lymph node** the rounded follicles of lymphocytes are concentrated at the periphery (cortex), but these are not the only lymphocytes in the node. There are others (not collected into follicles) in regions adjacent to the cortex — the paracortical areas — and also in the medullary region at the hilum of the node where the efferent lymphatic vessels leave. B lymphocytes are found in the follicles (in whose germinal centres they proliferate) and medulla, and T lymphocytes in the paracortical areas (the thymus-dependent zone) and in the cortex between follicles. The nodes receive afferent lymph vessels as well as draining by efferent channels; they act as filters as well as being a source of lymphocytes. (Thymus and spleen have no afferent lymphatics).

The (palatine and pharyngeal) **tonsils** possess lymphoid follicles similar to those of lymph nodes, but while the nodes simply have a capsule of connective

tissue the tonsils have on their inner surfaces a covering of stratified squamous epithelium that dips down deeply to form the tonsillar crypts. The presence of this epithelium distinguishes tonsils from lymph nodes histologically.

The lymphoid follicles of the **spleen** which collectively form its 'white pulp' are scattered among the sinusoids or 'red pulp'. The splenic follicles have a unique identifying feature: an arteriole courses through them, near but not through their germinal centres. Of course, in random histological sections not every follicle will be cut in a plane that displays the arteriole, but when seen it is pathognomonic of spleen, which also has a thick connective tissue capsule with trabeculae extending inwards from it. T cells are found in the immediate periarteriolar region of the follicle, with B cells in the germinal centre and other parts.

Apart from lymphocytes, all lymphoid organs contain phagocytic cells (macrophages, histiocytes) as part of the reticuloendothelial (monocyte-macrophage) system.

PART 2 NERVOUS SYSTEM

For convenience of description the nervous system is divided into the **central nervous system**, which consists of the brain and spinal cord (spinal medulla), and the **peripheral nervous system** composed of cranial and spinal nerves and their associated ganglia. The central and peripheral parts each have somatic and autonomic components; the somatic are concerned with the innervation of skeletal muscle (along efferent pathways) and the transmission of sensory information (along afferent pathways), and the autonomic are concerned with the control of cardiac muscle, smooth muscle and glands (involving afferent and efferent pathways). The term **autonomic nervous system**, which can be applied collectively to all autonomic components, i.e. those that control the internal environment of the body, is again a descriptive term of convenience and must not be taken as implying something anatomically separate. Indeed, functionally there is only one nervous system, with a basically simple plan of afferent (sensory) and efferent (motor) pathways, together with interconnexions (which in the central nervous system can be highly complex).

The central nervous system is described on page 577 and the peripheral and autonomic parts are considered with the appropriate regions of the body. Here some basic principles of neural organization are dealt with.

NEURONS AND NERVES

The structural and functional unit of the nervous system is the **nerve cell** or **neuron**. It consists of a part containing the nucleus, the *cell body*, and a variable number of processes commonly called *nerve fibres*. A single cytoplasmic process, the **axon** (often very long), conducts nerve impulses away from the cell body, and may give off many collaterals and terminal branches to many different target cells. Other multiple cytoplasmic processes, the **dendrites** (usually very short), expand the surface area of the cell body for the reception of stimuli. In everyday medical parlance the word neuron is often used to mean the cell body of the nerve cell, but it should be remembered that such use is not strictly correct since the word properly means not only the cell body but all its processes as well.

Pathways are established in the nervous system by communications between neurons at **synapses**, which are sites on the cell body or its processes where chemical transmitters enable nerve impulses to be handed on from one neuron to another. Often, in sympathetic ganglia for example, there are many more synapses on dendrites than on the cell bodies. The small number of 'classical' transmitters such as acetylcholine and noradrenaline (norepinephrine) has been vastly supplemented in recent years by many others which may not only be neurotransmitters but have endocrine functions as well, and may be found in many parts of the body apart from the nervous system. They are variously grouped as neuroendocrine cells, neuro-mediators or APUD cells (amine precursor uptake and decarboxylation), and may collectively form a *diffuse neuroendocrine system*. Specialist texts and journals must be consulted for the current status of their components and functions.

Cell bodies with similar function show a great tendency to group themselves together, forming *nuclei* within the central nervous system and *ganglia* outside it. Similarly processes from such aggregations of cell bodies tend to run together in bundles, forming *tracts* within the central nervous system and *nerves* outside the brain and spinal cord. The fibres of peripheral nerves are often loosely called axis cylinders or axons despite the fact that functionally many of them may be dendrites.

Apart from neurons the nervous system contains other cells collectively known as **neuroglial cells** (neuroglia, or simple glia or glial cells), which have supporting and other functions, but which do not have the property of excitability or conductivity possessed by neurons. The main types of neuroglial cell are *astrocytes* and *oligodendrocytes*, which like neurons are developed

from ectoderm of the neural tube. A third type of neuroglial cell is the *microglial cell* (microglia) which is the phagocytic cell of the nervous system, corresponding to the macrophage of connective tissue and which is derived from mesoderm. The *satellite cells* of ganglia outside the central nervous system and the *Schwann cells* of peripheral nerves are derived from ectoderm of the neural tube and constitute the glial cells of the peripheral nervous system.

Nerve fibres may be **myelinated** or **unmyelinated**. In the central nervous system myelin is formed by oligodendrocytes, and in peripheral nerves by Schwann cells (still the commonly used name for what are now properly called *neurolemmocytes*). In myelinated fibres, the regions where longitudinally adjacent Schwann cells or oligodendrocyte processes adjoin one another are the nerve fibre *nodes* (of Ranvier). The white matter of the nervous system is essentially a mass of nerve fibres and is so called because of the general pale appearance imparted by the fatty myelin, in contrast to grey matter which is darker and consists essentially of cell bodies. Further details of the cellular composition of nervous tissue will be found in textbooks of histology, but it is relevant to regional anatomy to note the varying sizes of peripheral nerve fibres and the functions that can be associated with them (with an alternative classification for afferent fibres):

- Group A: up to 20 μm diameter, subdivided into —
 - α : 12–20 μm . Motor and proprioception (Ia and Ib)
 - β : 5–12 μm . Touch, pressure and proprioception (II)
 - γ : 5–12 μm . Fusimotor to muscle spindles (II)
 - δ : 1–15 μm . Touch, pain and temperature (III).
- Group B: up to 3 μm diameter. Myelinated. Preganglionic autonomic.
- Group C: up to 2 μm diameter. Unmyelinated. Postganglionic autonomic, and touch and pain (IV).

Unfortunately, as can be seen from the above, it is not possible to make a precise prediction of function from mere size. Thus the largest myelinated fibres may be motor or proprioceptive and the smallest, whether myelinated or unmyelinated, are autonomic or sensory.

Spinal nerves

There are 31 pairs of **spinal nerves** — 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal. Each spinal nerve is formed by the union of an **anterior** (ventral) and **posterior** (dorsal) **root** which emerge from the side of the spinal cord. The union does not take place adjacent to the cord but within the intervertebral foramen of the appropriate nerve, immediately distal to the swelling on the posterior root which

indicates the site of the **posterior root ganglion** and which is also within the foramen. The anterior root of every spinal nerve contains motor (efferent) fibres for skeletal muscle; those from T1 to L2 inclusive and from S2 to S4 also contain autonomic fibres. Although hitherto regarded as containing only efferent fibres, it is now known that the anterior root also contains a small number of unmyelinated afferent pain fibres which have 'doubled back' from their cells of origin in the posterior root ganglion to enter the spinal cord by the anterior root instead of by the expected posterior root. The posterior root of every nerve contains sensory (afferent) fibres whose cell bodies are in the posterior root ganglion. There are no synapses in these ganglia; it is simply the site of the cell bodies.

Immediately after its formation the spinal nerve divides into an **anterior** and a **posterior ramus** (formerly known as 'primary' rami, but since there is nothing called a secondary ramus the unnecessary adjective has been dropped). The great nerve plexuses — cervical, brachial, lumbar and sacral — are formed from anterior rami; posterior rami do not form plexuses. Very often the posterior ramus appears to be a direct branch from the posterior root ganglion, so that macroscopically there appears to be no spinal nerve proper; at best it is only a millimetre or two long.

Connective tissue binds the individual fibres of spinal nerves together to form the single nerve. In all but the very smallest nerves the fibres are collected together into several rounded bundles or fascicles, each surrounded by *perineurium*, a condensation of connective tissue easily seen in transverse histological sections. The *epineurium* is the rather looser tissue which binds the fascicles into a single nerve, while *endoneurium* is the name given to the very finest fibrils (visible only with the electron microscope) which surround every single nerve fibre. In the largest nerve, the sciatic, only about 20% of the cross-sectional area is nerve, so 80% is connective tissue, but in smaller nerves the amount of neural tissue is proportionally greater. In the same way that the larger blood vessels have their own vessels in their walls (*vasa vasorum*), so the larger nerves have their own nerves, the *nervi nervorum*, in their connective tissue coverings. The presence of these neglected structures in, for example, the sciatic nerve explains the distribution of pain in some inflammatory affections of the nerve.

Blood supply of nerves

Peripheral nerve trunks in the limbs are supplied by branches from local arteries. The sciatic nerve in the buttock and the median nerve at the elbow have each a large branch from the inferior gluteal and common

interosseous arteries respectively, each the former axial artery of the limb. Elsewhere, however, regional arteries supply nerves by a series of longitudinal branches which anastomose freely within the epineurium, so that nerves can be displaced widely from their beds without risk to their blood supply. The phrenic nerve, finding no regional artery in its course through the mediastinum, takes its own artery with it (the pericardiophrenic artery, p. 261).

GENERAL PRINCIPLES OF NERVE SUPPLY

Once the nerve supply to a part is established in the embryo it never alters thereafter, unlike the vascular supply. However far a structure may migrate in the developing fetus it always drags its nerve with it. Conversely, the nerve supply to an adult structure affords visible evidence of its embryonic origin.

Skeletal muscles are innervated from motor neuron 'pools' — groups of motor nerve cell bodies in certain cranial nerve nuclei of the brainstem and anterior horns of the spinal cord. The pool supplying any one muscle overlaps the pools of another, e.g. the anterior horn cells of spinal cord segments C5 and 6 that supply deltoid are intermixed with cells of the same segments supplying subscapularis and other muscles. The only exceptions to the overlapping of neuronal pools are the brainstem nuclei of the fourth and sixth cranial nerves, since they are the only motor nerve cell groups supplying only one muscle (superior oblique and lateral rectus of the eye respectively).

The branches of spinal nerves that are called 'somatic motor nerves' (e.g. to limb muscles) are not purely motor, since they also contain afferent fibres from those muscles and from joints and ligaments, i.e. fibres of postural sensibility or proprioception. It follows that 'mixed nerves' with motor and cutaneous fibres must also contain proprioceptive fibres, but purely 'cutaneous nerves' which carry touch, pain and temperature fibres do not have those of proprioceptive sensibility. Lesions of motor and mixed nerves will therefore cause proprioceptive as well as motor loss, but lesions of cutaneous nerves will not cause proprioceptive loss.

NERVE SUPPLY OF THE BODY WALL

The body wall is supplied segmentally by spinal nerves (Fig. 1.10). The posterior rami pass backwards and supply the extensor muscles of the vertebral column and skull, and to a varying extent the skin that overlies them. The anterior rami supply all other muscles of the trunk and limbs and the skin at the sides and front of the neck and body.

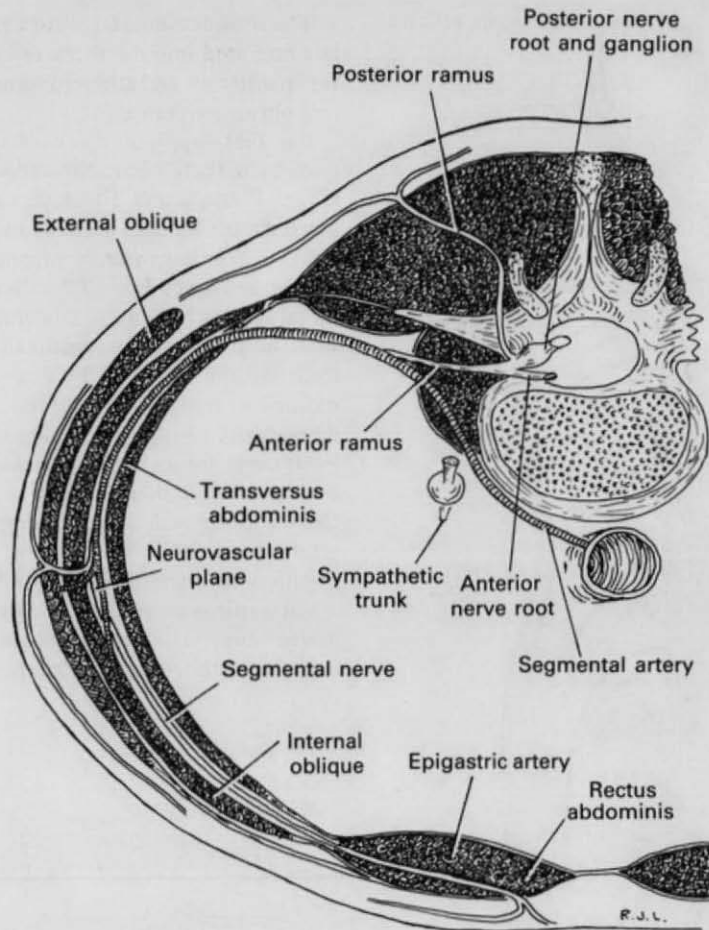


Fig. 1.10 Neurovascular plane of the body wall, between the inner and middle of the three muscle layers. Where the spinal nerve and segmental artery cross, the nerve lies nearer the skin. The segmental nerve enters rectus abdominis (usually behind rather than in front of the epigastric arteries, as shown here) and passes to the overlying skin, but the segmental artery ends in the flank muscles. The sympathetic trunk lies vertically within the circle of the segmental artery.

Posterior rami

In the trunk all the muscles of the erector spinae and transversospinalis groups that lie deep to the thoracolumbar fascia, and the levator costae muscles of the thorax (which belong morphologically to the extensor groups) are supplied segmentally by the posterior rami of spinal nerves. In the neck splenius and all muscles deep to it are similarly supplied.

The cutaneous distribution of the posterior rami extends further out than the extensor muscles — almost to the posterior axillary lines. It is to be remembered that:

- (1) Each posterior ramus divides into a medial and a

lateral branch (Fig. 1.10). Both branches of *all* the posterior rami supply muscle, but only one branch, either medial or lateral, reaches the skin.

(2) C1 has no cutaneous branch, and the posterior rami of the lower two nerves in the cervical and lumbar regions of the cord likewise fail to reach the skin. All 12 thoracic and 5 sacral nerves reach the skin.

(3) In the upper half of the body the medial branches, and in the lower half the lateral branches, of the posterior rami provide the cutaneous branches (Fig. 1.11).

(4) No posterior ramus ever supplies skin or muscle of a limb in any vertebrate.

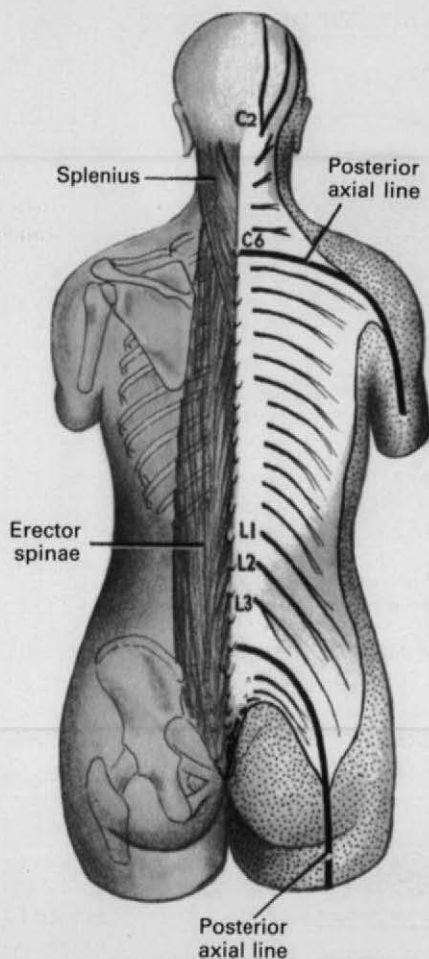


Fig. 1.11 Distribution of posterior rami. On the right the cutaneous distribution is shown (medial branches down to T6, to clear the scapula, and lateral branches below this); the stippled areas of skin are supplied by anterior rami. On the left the muscular distribution is shown, to erector spinae and to splenius and the muscles deep to it.

Anterior rami

The anterior rami supply the prevertebral flexor muscles segmentally by separate branches from each nerve (e.g. longus capitis, scalene muscles, psoas, quadratus lumborum, piriformis). The anterior rami of the 12 thoracic nerves and L1 supply the muscles of the body wall segmentally. Each intercostal nerve supplies the muscles of its intercostal space, and the lower six nerves pass beyond the costal margin to supply the muscles of the anterior abdominal wall. The first lumbar nerve (iliohypogastric and ilioinguinal nerves) is the lowest spinal nerve to supply the anterior abdominal wall.

The muscle below L1 is no longer in the body wall; it has migrated into the thigh to become specialized into the quadriceps and adductor group of muscles (femoral and obturator nerves).

For skin supply in the neck only C2, 3 and 4 take part, by branches from the cervical plexus. The skin of C5, 6, 7 and 8 and T1 clothes the upper limb, innervated via the brachial plexus from these segments.

In the trunk the skin is supplied in strips or zones in regular sequence from T2 to L1 inclusive. The intercostal nerves have each a lateral branch to supply the sides and an anterior terminal branch to supply the front of the body wall (Fig. 1.12). The lower six thoracic nerves pass beyond the costal margin obliquely downwards to supply the skin of the abdominal wall. Each nerve throughout the whole of its course supplies a strip of skin that overlies it (a *dermatome*, p. 22). On the body wall adjacent dermatomes overlap considerably, so that interruption of a single segment produces no anaesthesia (Fig. 1.12).

Each spinal nerve contains a mixture of sensory and motor fibres. The lateral branch and anterior terminal branch of the *intercostal* nerve perforate muscles to

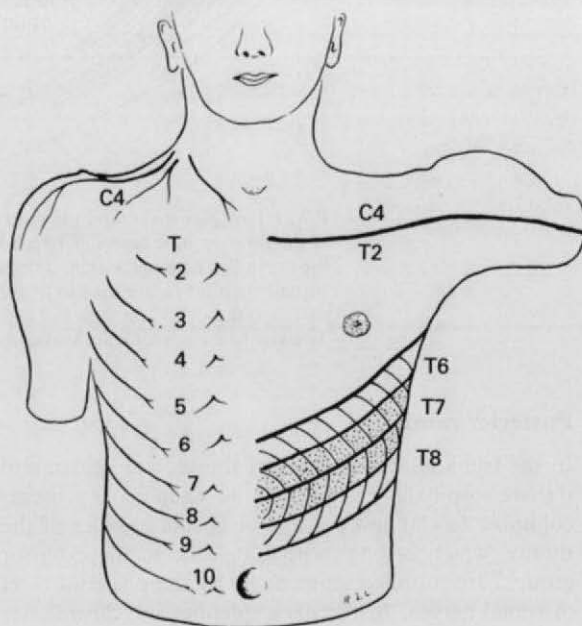


Fig. 1.12 Overlap of dermatomes on the body wall. On the right side the supraclavicular and thoracic nerves are shown; on the left the anterior axial line is indicated. The dermatomes of T6 and 8 meet each other, completely covering T7, explaining why division of a single intercostal nerve does not give rise to anaesthesia on the trunk.

reach the deep fascia and skin. The collateral branches contain motor fibres only.

Neurovascular plane

The nerves of the body wall, accompanied by their segmental arteries and veins, spiral around the walls of the thorax and abdomen in a plane between the middle and deepest of the three muscle layers (p. 244). In this neurovascular plane the nerves lie below the arteries as they run around the body wall. But the nerves cross the arteries posteriorly alongside the vertebral column and again anteriorly near the ventral midline, and at these points of crossing a definite relationship is always maintained between the two. *The nerve always lies nearer the skin.* The spinal cord lies nearer the surface of the body than the aorta, and as a result the spinal nerve makes a circle that surrounds the smaller arterial circle. The arterial circle is made of the aorta with its intercostal and lumbar arteries, completed in front by the internal thoracic and the superior and inferior epigastric arteries. As a part of the same arterial pattern the vertebral arteries pass up to the cranial cavity. The spinal nerves, as they emerge from the intervertebral foramina, pass laterally behind the vertebral artery in the neck, behind the posterior intercostal arteries in the thorax, behind the lumbar arteries in the abdomen and behind the lateral sacral artery in the pelvis. The anterior terminal branches of the spinal nerves similarly pass in front of the internal thoracic and the superior and inferior epigastric arteries (Fig. 1.10).

The sympathetic trunk does not lie in the neurovascular plane but it is useful to remember that it runs vertically within the arterial circle. From the base of the skull to the coccyx the sympathetic trunk lies anterior to the segmental vessels (vertebral, posterior intercostal, lumbar and lateral sacral arteries) which, as already seen, lie anterior to the spinal nerves (Fig. 1.10).

Sympathetic fibres

Every spinal nerve without exception, from C1 to the coccygeal, carries postganglionic (unmyelinated, grey) sympathetic fibres which 'hitch-hike' along the nerves and accompany all their branches. They leave the spinal nerve only at the site of their peripheral destination. They are in the main vasoconstrictor in function, though some go to sweat glands in the skin (sudomotor) and to the arrectores pilorum muscles of the hair roots (pilomotor). In this way the sympathetic system innervates the whole body wall and all four limbs. This is chiefly for the function of temperature regulation. The visceral branches of the sympathetic system have a different manner of distribution (p. 31).

NERVE SUPPLY OF LIMBS

The body wall has been seen to be supplied segmentally by spinal nerves (Fig. 1.10). A longitudinal strip posteriorly is supplied by posterior rami, a lateral strip by the lateral branches of the anterior rami, and a ventral strip by the anterior terminal branches of the anterior rami. In all vertebrates the limb buds grow out from the lateral strip supplied by the lateral branches of the anterior rami (Fig. 1.13) and these lateral branches, by their anterior and posterior divisions, form the plexuses for supply of the muscles and skin of the limbs (Fig. 1.14). The posterior divisions supply extensor muscles and skin of the limbs. The anterior divisions generally represent fusion of the anterior division of the lateral branch with the anterior terminal branch. They supply flexor muscles and skin of the limbs.

Each limb consists of a flexor and an extensor compartment, which meet at the preaxial and postaxial borders of the limb. These borders are marked out conveniently by veins. In the upper limb the cephalic vein lies at the preaxial and the basilic vein at the postaxial border. In the lower limb extension and medial rotation, which replace the early fetal position of flexion, have complicated the picture. The great saphenous vein marks out the preaxial and the small saphenous vein the postaxial borders of the limb.

Limb plexuses

In all vertebrates the skin and muscles of the limbs are supplied by plexuses. The plexuses are formed from the anterior rami, never from the posterior rami, of spinal nerves. The spinal nerves entering into a limb plexus



Fig. 1.13 Origin of the limb buds. The body wall is innervated in three longitudinal strips, and the embryonic limb bud grows out from the lateral (middle) strip, supplied by lateral branches of the anterior rami.

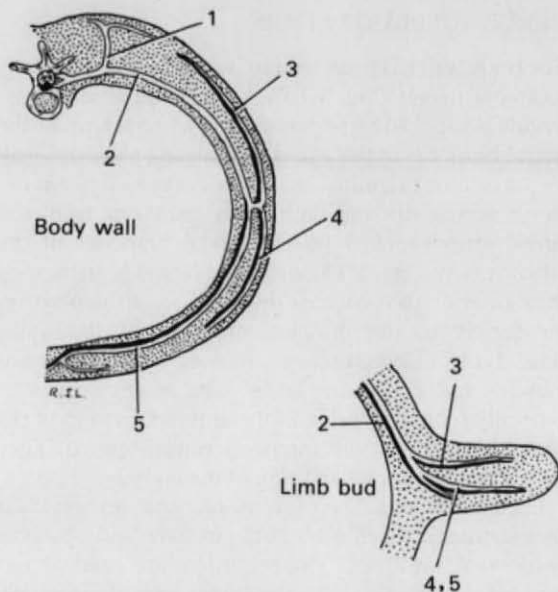


Fig. 1.14 Typical body wall nerve and its incorporation into a limb plexus. The numbers in the two diagrams indicate corresponding structures. 1 — Posterior ramus, 2 — anterior ramus, 3 — posterior branch of lateral branch of spinal nerve in body wall and posterior division of limb plexus in limb bud, 4 — anterior branch of lateral branch of spinal nerve in body wall and anterior division of limb plexus in limb bud, 5 — anterior terminal branch of spinal nerve in body wall, incorporated into the anterior division of the limb plexus.

come from enlarged parts of the cord, the cervical enlargement for the brachial plexus and the lumbar enlargement for the lumbar and sacral plexuses. The enlargements are produced by the greatly increased number of motor neurons in the anterior horns at these levels (p. 621).

Because of the way nerve fibres become combined and rearranged in plexuses, any one spinal nerve can contribute to more than one peripheral nerve and peripheral nerves can receive fibres from more than one spinal nerve. It follows that the area of skin supplied by any one spinal nerve or spinal cord segment (dermatome — see below) is not the same as the area supplied by the particular spinal nerve. It is therefore necessary to learn two kinds of skin maps or charts — one showing segmental innervation and the other showing peripheral nerves. The segmental supplies are reviewed below; the peripheral nerves of the upper and lower limbs are summarized on pages 120 and 212.

The constituents of every limb plexus divide into anterior and posterior divisions. The anterior divisions supply the flexor compartment and the posterior divisions supply the extensor compartment of the limb.

The flexor compartment has a richer nerve supply than the extensor compartment; this applies to both skin and muscle supplies. The richer innervation, both sensory and motor, of the flexor compartment shows in the fact that the *most caudal root of a limb plexus is distributed entirely to the flexor compartment of the limb*. This is T1 in the brachial plexus (apart from a small area of skin innervated by the posterior cutaneous nerve of the arm none of this segment supplies the extensor compartment) and S3 in the sacral plexus — no S3 enters the extensor compartment of the lower limb (peroneal nerve). Note the composition of the two parts of the sciatic nerve:

tibial division L4, 5, S1, 2, 3
peroneal division L4, 5, S1, 2.

Double innervation of muscles

In a few cases muscles near the preaxial or postaxial border of a limb receive a double nerve supply. Generally they are flexor muscles that receive a supply from the nerve of the extensor compartment. This apparent contradiction is due to embryological causes, namely that the muscle concerned was developed in the extensor compartment of the fetal limb but lies, for functional reasons, in the flexor compartment of the adult limb, bringing its nerve with it. The lateral portion of brachialis (supplied by the radial nerve) and the short head of biceps femoris (supplied by the peroneal part of the sciatic nerve) are examples of flexor muscles supplied by extensor compartment nerves, and in each case the remainder of the muscle is, in fact, supplied by a flexor compartment nerve.

In the arm the intermuscular septum between the flexor and extensor compartments does not represent the fetal septum. In the fetus the ulnar nerve was in the flexor compartment, while brachioradialis, the lateral part of brachialis, and the radial nerve were in the extensor compartment (Fig. 1.15). The adult septum imprisons the ulnar nerve in the extensor compartment above the elbow and brachioradialis, the lateral part of brachialis and the radial nerve in the flexor compartment.

SEGMENTAL INNERVATION OF THE SKIN

The area of skin supplied by a single spinal nerve is called a **dermatome**. On the trunk adjacent dermatomes overlap considerably, and so it is on the limbs except at the axial lines. The skin that envelops a limb is drawn out over the developing limb from the

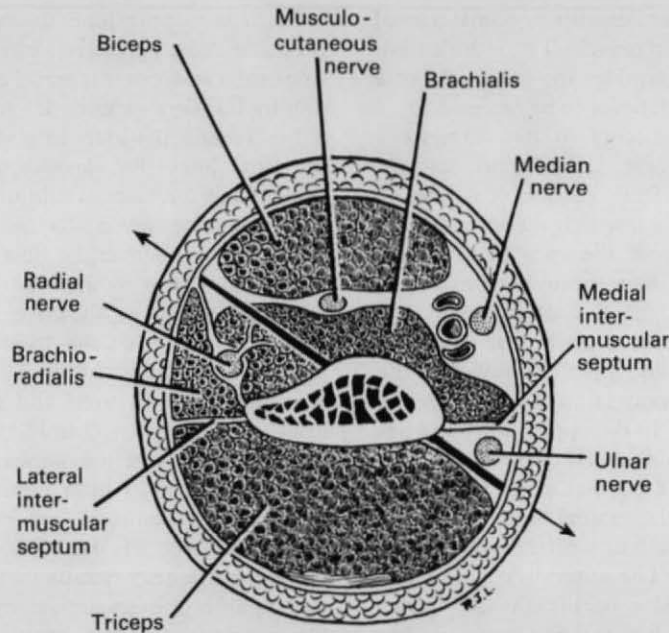


Fig. 1.15 Cross-section of the arm above the elbow. The arrows indicate the site of the fetal intermuscular septum between the flexor and extensor compartments. In the fetus the radial nerve and its adjoining muscles lie in the extensor compartment, and the ulnar nerve in the flexor compartment.

trunk, and study of the trunk dermatomes near the root of a limb shows that here many of the dermatomes are missing; they lie out along the limb. The line of junction of two dermatomes supplied from discontinuous spinal levels is known as an **axial line**, and such axial lines extend from the trunk on to the limbs.

In the **upper limb** (Fig. 1.16) the anterior axial line runs from the sternal angle across the second costal cartilage and down the front of the limb almost to the wrist. Similarly a posterior axial line is said to run from the vertebra prominens across the back and down the back of the arm only as far as the insertion of the deltoid muscle.

The central dermatome of the limb plexus (C7) clothes the peripheral extremity of the limb. More cranially disposed segments are distributed to dermatomes along the preaxial border of the limb and more caudally disposed dermatomes lie along the postaxial border. There is much overlap between adjacent dermatomes but *no overlap across axial lines*, a point of great clinical value to remember when investigating cutaneous paraesthesia of segmental origin. Always test across axial lines. Note that the dermatomes lie in orderly numerical sequence when traced distally down the front and proximally up the

back of the anterior axial line (C5, 6, 7, 8, and T1) and that these dermatomes belong to the nerves of the brachial plexus. In addition, skin has been 'borrowed'

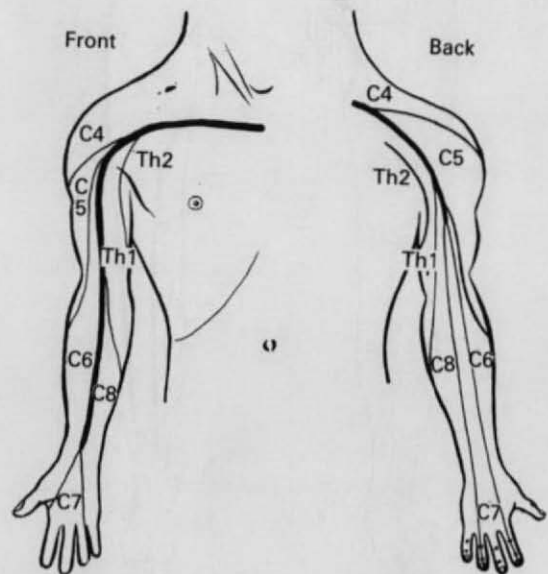


Fig. 1.16 Approximate dermatomes and axial lines of the right upper limb. See text for explanation.

from the neck and trunk to clothe the proximal part of the limb (C4 over the deltoid muscle, T2 for the axilla). The 'borrowing' of skin resembles the borrowing of a book by a friend ('borrowed, never to be returned').

Considerable distortion occurs to the dermatome pattern of the **lower limb** (Fig. 1.17) for two reasons. Firstly the limb, from the fetal position of flexion, is medially rotated and extended, so that the anterior axial line is caused to spiral from the root of the penis (clitoris) across the front of the scrotum (labium majus) around to the back of the thigh and calf in the midline almost to the heel. Secondly, a good deal of skin is 'borrowed' from the trunk, and it is all borrowed on the cranial side (there is no skin caudal to the limb except a small area of perianal skin). In the upper limb there has been symmetrical cranial and caudal borrowing of skin (a little of C4 and a little of T2) but in the lower limb four dermatomes, all on the cranial side, have been borrowed from beyond the limits of the limb plexus (from T12, L1, 2 and 3). The anterior axial line has been described. The posterior axial line is said to run from the fourth lumbar interspace (the site of a lumbar puncture) in a bold convexity to the back of the thigh down to the head of the fibula and thence halfway down the calf.

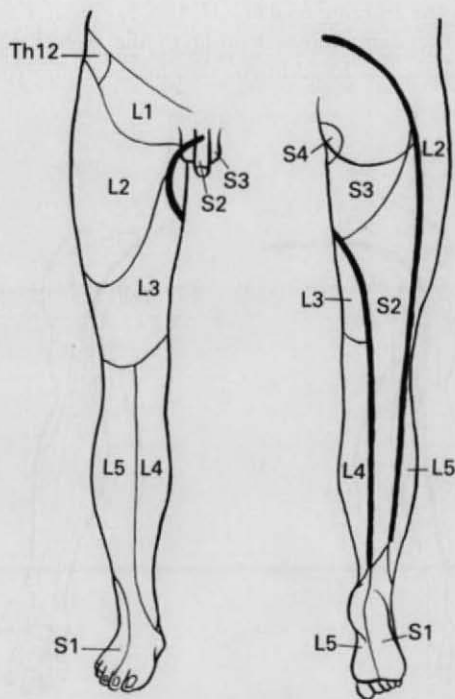


Fig. 1.17 Approximate dermatomes and axial lines of the right lower limb. See text for explanation.

As in the upper limb the central root of the limb plexus is most peripheral, extending on to the lateral side of the sole, but it is joined on the medial side of the foot by L5. One walks on L5 and S1 and sits on S3, for it lies around the anus in a wide semicircle between the axial lines (S4 supplies the immediate perianal skin). S2 is the narrow strip up the middle of the calf and hamstrings joining S1 and S3 and limited by the axial lines. L4 is over the tibia and L5 over the fibula but extends also to include the big toe. The other dermatomes are as shown in Figure 1.17, they are borrowed skin from the trunk. Note that, as in the upper limb, the dermatomes can be traced in numerical sequence down in front and up behind the anterior axial line (L1, 2, 3, 4, 5 and S1, 2, 3).

Thus each anterior ramus, passing through the ramifications of its limb plexus, is paid off into the appropriate cutaneous nerves and finally reaches its allotted area of skin (i.e. the dermatome). The **sympathetic grey ramus** that joins each spinal nerve accompanies it to its dermatome (where it is temperature-regulating). Thus knowledge of the segmental supply of an area of skin tells also the site of the cell body of the sympathetic nerve in that area (p. 32).

A practical application of the anterior axial line arises in spinal analgesia. A 'low spinal' (caudal) anaesthesia anaesthetizes skin of the posterior two-thirds of the scrotum or labium majus (S3), but to anaesthetize the anterior one-third of the scrotum or labium L1 must be involved, an additional seven spinal segments higher up.

It must be remembered that a single chart cannot indicate individual variations or the differing findings of several groups of investigators, and that such charts are a compromise between the maximal and minimal segmental areas which experience has shown can occur. Original charts, such as those made by Sherrington, Head and Foerster, are being modified by the continuing accumulation of new information. Thus T1 nerve, for example, is not usually considered to supply any thoracic skin but has sometimes been considered to do so, and L5 and S1 have been reported to extend to buttock skin although this is not usually expected. It is probable that posterior axial lines do not exist, but evidence for anterior axial lines is more convincing. Difficulty in investigation arises in the main from the blurring of patterns due to overlap from adjacent dermatomes, and is enhanced by the rarity of a lesion that is complete in one single root without involving others. Despite these complications a chart of dermatomes must be learned, on the understanding that it must be interpreted with flexibility. The following summary (which for the reasons stated above

is not necessarily identical with the information given in Figs 1.16 and 1.17) offers selected guidelines that are clinically useful:

- C1 — no skin supply
 - C2 — occipital region and posterior neck
 - C3 — posterior neck and supraclavicular region
 - C4 — infraclavicular region (over first thoracic interspace) to tip of shoulder and above scapular spine
 - C5 — lateral arm (over deltoid and below)
 - C6 — lateral forearm, thumb and probably index finger
 - C7 — middle finger
 - C8 — ring and little fingers, and distal medial forearm
 - T1 — medial elbow (not the axilla)
 - T2 — medial arm, axilla and thorax (adjoining C3 and 4)
 - T3 — thorax and small extension to axilla
 - T4 — nipple (T5 according to some authorities)
 - T8 — rib margin
 - T10 — umbilicus
 - T12 — suprapubic, upper buttock
 - L1 — inguinal region, anterior scrotum (labia), upper buttock
 - L2 — anterior thigh, upper buttock
 - L3 — anterior and medial knee, upper buttock
 - L4 — medial leg, medial malleolus and side of foot
 - L5 — lateral leg, dorsum and medial side of foot, medial sole
- Note that L5 supplies the dorsum and sole of the foot, and while L4 may extend along the medial side of the great toe, this toe is usually supplied by L5
- S1 — lateral malleolus, lateral side of dorsum and sole
- Note that like L5, S1 supplies some of the dorsum and sole
- S2 — posterior leg, posterior thigh, buttock, penis
 - S3 — sitting area of buttock, posterior scrotum (labia)
 - S4 — perianal
 - S5 and Co — behind anus and over coccyx.

SEGMENTAL INNERVATION OF MUSCLES

A **myotome** is the amount of muscle supplied by one segment of the spinal end. The regular sequence of myotomes in the trunk (p. 18) appears at first sight to be broken up into a bewildering complexity of myotomes in the limbs. Knowledge is required on two points: (1) what is the segmental supply of this particular limb muscle, and (2) what is the total muscular distribution of this particular spinal segment? It is an enormous task to attempt the memorizing of muscle and nerve lists and, what is more, it is unnecessary,

since the underlying plan of segmental innervation is very simple. It is based on the following four facts:

(1) Most muscles are supplied equally from two adjacent segments (but some, especially in the upper limb, are predominantly unisegmental).

(2) Muscles sharing a common primary action on a joint irrespective of their anatomical situation are all supplied by the same (usually two) segments.

(3) Their opponents, sharing the opposite action, are likewise all supplied by the same (usually two) segments and these segments usually run in numerical sequence with the former.

(4) For joints distal in the limbs the spinal centre lies lower in the cord. For a joint one segment more distal in the limb the centre lies en bloc one segment lower in the cord.

Thus there are in effect *spinal centres* for joint movements, and these centres tend to occupy continuous segments in the cord. The upper one or two segments innervate one movement, and the lower one or two innervate the opposite movement (although sometimes the same segment may innervate both movements, but of course from different anterior horn cells). Thus the spinal centre for the elbow is in C5, 6, 7, 8 segments and C5, 6 supply the flexors and C7, 8 the extensors of the joint. If the elbow be flexed while the numbers 5, 6 are recited, and extended to the numbers 7, 8, one only needs to perform this simple movement to the numbers 5–6 and 7–8 a few times to learn that biceps, brachialis and brachioradialis (the prime flexors of the elbow) are supplied by C5, 6 and that triceps (the prime extensor of the elbow) is supplied by C7, 8.

The segments *mainly* responsible for the various limb joint movements are summarized in Figures 1.18 and 1.19. Flexion/extension at the hip, knee and ankle are the easiest to remember, for each movement involves two segments in logical sequence for each joint, and for each more distal joint segments concerned are one segment lower. For the other movements, and especially in the upper limb, the arrangements are not quite so neat, but a few minutes spent reciting the numbers while performing the movements will soon commit them to memory.

Hip	Knee	Ankle
2 } Flex	3 } Extend	4 } Dorsiflex
3 }	4 }	5 }
4 } Extend	5 } Flex	1 } Plantarflex
5 }	1 }	2 }

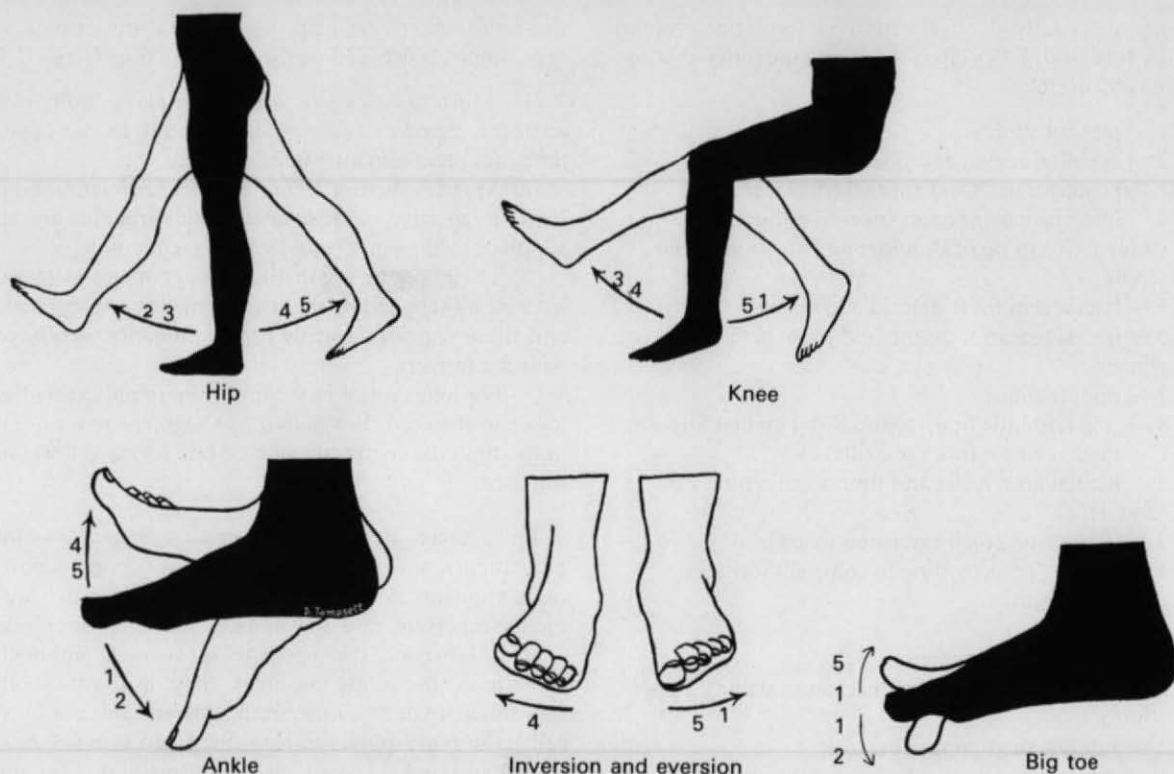


Fig. 1.18 Segmental innervation of movements of the lower limb.

It is cumbersome to print all this in black and white, but very easy to demonstrate it (similar, for instance to teaching the steps of a dance or the movements of an exercise).

To illustrate by a few examples:

Iliacus (flexes hip) L2, 3

Biceps (flexes knee) L5, S1

Soleus (plantarflexes ankle) S1, 2

The above are simple flexion-extension movements and, indeed, cover all knee- and ankle-moving muscles. At the hip, however, movements other than flexion extension are possible, but *all innervated by the same four segments*. Thus:

Adduction or medial rotation (same as flexion) L2, 3

Abduction or lateral rotation (same as extension) L4, 5

There remains one other movement of the lower limb, namely **inversion** and **eversion** of the foot, the formula being:

Invert foot L4

Evert foot L5, S1

Note that tibialis anterior and tibialis posterior invert

the foot and both are innervated by L4 segment. Tibialis anterior is also a dorsiflexor and L4, 5 (from the formula already given for dorsiflexion) is approximately correct. Tibialis posterior, however, lies deep among the plantar flexors of the ankle (S1, 2) and it is illuminating to find this solitary muscle innervated from quite a different level from its neighbours — but a level that coincides with its inverting partner, the anterior tibial.

Only one more point need be explained about the lower limb; it concerns the muscles of the buttock. The simple formula given above shows extension, abduction and lateral rotation of the hip as L4, 5 and this covers all the muscles of the buttock. It is, indeed, accurate enough for most purposes in clinical investigation, but for those readers who require more detailed information the following analysis has greater precision:

Nerve to quadratus femoris and inferior gemellus L4, 5, S1 — superior gluteal nerve (glutei medius, minimus and tensor fasciae latae).

Nerve to obturator internus and superior gemellus L5, S1, 2 — inferior gluteal nerve (gluteus maximus).

In short, obturator internus and gluteus maximus are

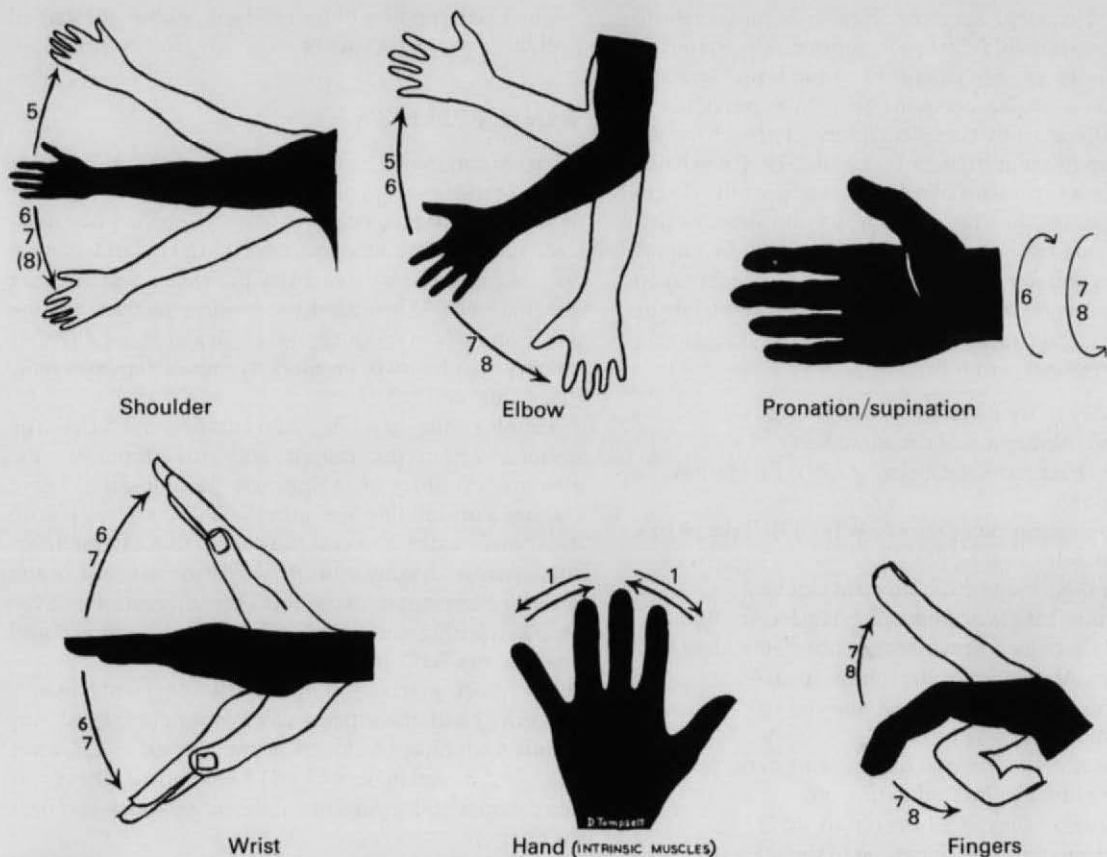


Fig. 1.19 Segmental innervation of movements of the upper limb.

supplied by 5, 1, 2, all the other buttock muscles by 4, 5, 1.

The **upper limb** movements, with the segments involved (Fig. 1.19), are as follows:

<i>Shoulder</i>	Abduct and laterally rotate C5 Adduct and medially rotate C6, 7, 8
<i>Elbow</i>	Flex C5, 6 Extend C7, 8
<i>Forearm</i>	Pronate C7, 8 Supinate C6
<i>Wrist only</i>	Flex C6, 7 Extend C6, 7
<i>Fingers and thumb</i> (long tendons)	Flex C7, 8 Extend C7, 8
<i>Hand</i> (intrinsic muscles)	T1

In the upper limb the two-and-two segment pattern is not as regular as in the lower limb, probably because in the upper limb much more precise movements are

constantly being employed, and the spinal centres have broken up into separate nuclei to control these. Thus, below the elbow the plan does not conform to the basic pattern of four spinal segments for each joint. Flexion and extension share the same two segments; these are C6, 7 for the wrist and C7, 8 for the digits. But the rule holds that the more distal joints are innervated from lower centres in the cord.

The motor spinal centres for the joints of the limbs lie in cell aggregates in the lateral parts of the anterior grey horns in the cervical and lumbar enlargements of the cord. The medial parts of the anterior grey horns in the limb enlargements are in line with the slender grey horns of the thoracic region and, like them, supply segmentally the extensor and flexor muscles of the vertebral column and have nothing to do with the muscles of the limbs.

As with cutaneous nerve supplies, so with motor innervation: two categories of information are required — the segmental or root supplies, and the peripheral nerve supplies. The latter are considered with the

appropriate regional anatomy. Here it is convenient to summarize segmental or root supplies, indicating a single muscle or movement for which the segment concerned is *mainly* responsible, thus providing a slightly different but complementary approach to the information given in Figures 1.18 and 1.19. An exhaustive list of many muscles may be necessary for the neurological specialist, but the notes below, on muscles that can be tested easily or are otherwise clinically important, give a suitable indication of the control exerted on different parts of the body by the various levels of the spinal cord, and could be used for example as a guide to the level of spinal cord injury.

- C4 Diaphragm. Respiration (p. 250)
- C5 Deltoid. Abduction of the shoulder (p. 73)
- C6 Biceps. Flexion of the elbow (p. 79). Biceps jerk (see below)
- C7 Triceps. Extension of the elbow (p. 83). Triceps jerk (see below)
- C8 Flexor digitorum profundus and extensor digitorum. Finger flexion and extension (p. 91)
- T1 Abductor pollicis brevis representing small hand muscles. Abduction of the thumb (p. 109)
- T7–12 Anterior abdominal wall muscles (p. 300). Abdominal reflex (see below)
- L1 Lowest fibres of internal oblique and transversus, guarding the inguinal canal (p. 300)
- L2 Psoas major. Flexion of the hip (p. 153)
- L3 Quadriceps femoris. Extension of the knee (p. 157). Knee jerk (see below)
- L4 Tibialis anterior and posterior. Inversion of the foot (p. 208)
- L5 Extensor hallucis longus and peroneal muscles. Extension of the great toe and eversion of the foot (pp. 187 and 191)
- S1 Gastrocnemius. Plantarflexion of the foot (p. 194). Ankle jerk (see below)
- S2 Small muscles of the foot (p. 202)
- S3 Perineal muscles (p. 411). Bladder (parasympathetic) (p. 382). Anal reflex (see below) and bulbocavernosus reflex (see below).

It is important to note that the term 'root' as used in root injuries may be taken to mean either the nerve root proper, i.e. from the side of the spinal cord to the intervertebral foramen, or the roots of the plexuses, i.e. anterior rami distal to the foramen. In lesions of the nerve roots proper, sweating in the distribution of the appropriate nerves is normal, but in more peripheral lesions sweating is reduced, because the postganglionic sympathetic fibres from the sympathetic trunk join the nerves of plexuses distal to the nerve roots proper (Fig. 1.20C).

The nerve supplies of the *head* and *neck* are described with the appropriate regional anatomy, and on page 450.

SPINAL REFLEXES

What is commonly called the 'knee jerk' and similar tendon reflexes are typical examples of spinal myotatic or **stretch reflexes** (deep tendon reflexes). They illustrate the simplest kind of reflex pathway and involve only two neurons with one synapse (*monosynaptic reflex arc* (Fig. 1.20A)); indeed the tendon reflexes are the only examples of monosynaptic reflex arcs, for all other reflexes involve two or more synapses (*multisynaptic*, Fig. 1.20B and 1.20C).

Tapping the tendon momentarily stretches the spindles within the muscle and this stimulates the afferent (Ia) fibres of the primary (annulospiral) nerve endings surrounding the intrafusal fibres to pass into the spinal cord by the posterior nerve root. These afferents synapse directly with the α motor neurons of the anterior horn whose axons form the efferent side of the arc, so causing the extrafusal fibres to contract and produce the 'jerk' at the joint.

For most practical purposes the segments *mainly* concerned with the reflexes most commonly tested may be taken as: biceps jerk — C6, triceps jerk — C7, knee jerk — L3, ankle jerk — S1. (As noted above for dermatomes and myotomes, different textbook accounts may vary.)

Diminution or absence of the jerk usually indicates some kind of interruption of the arc or muscular defect, but *exaggeration* of the tendon reflexes is taken as evidence of an *upper motor neuron lesion* due to alterations in the supraspinal control of the anterior horn cells which are rendered unduly excitable. In this case the γ motor neurons of the anterior horn are stimulated by such fibres as the reticulospinal and vestibulospinal. The pathway (Fig. 1.20D) is from the γ motor neuron to the intrafusal muscle fibres of the spindle, then from the afferent fibres of the spindle to the α motor neuron and so to the extrafusal fibres. This is the γ reflex loop or *fusimotor neuron loop*.

In addition to the above deep tendon reflexes, there are superficial skin reflexes which are multisynaptic. Those most commonly tested are the plantar, abdominal, anal and bulbocavernosus reflexes.

Firm stroking of the lateral surface of the sole of the foot (as with the end of a key) to elicit the **plantar reflex** normally causes *plantarflexion* of the great toe and probably of the other toes as well. Extension of the great toe — the **extensor response** (*Babinski's sign*) — indicates an upper motor neuron lesion, and is one of the cardinal signs of clinical medicine (p. 625). Note

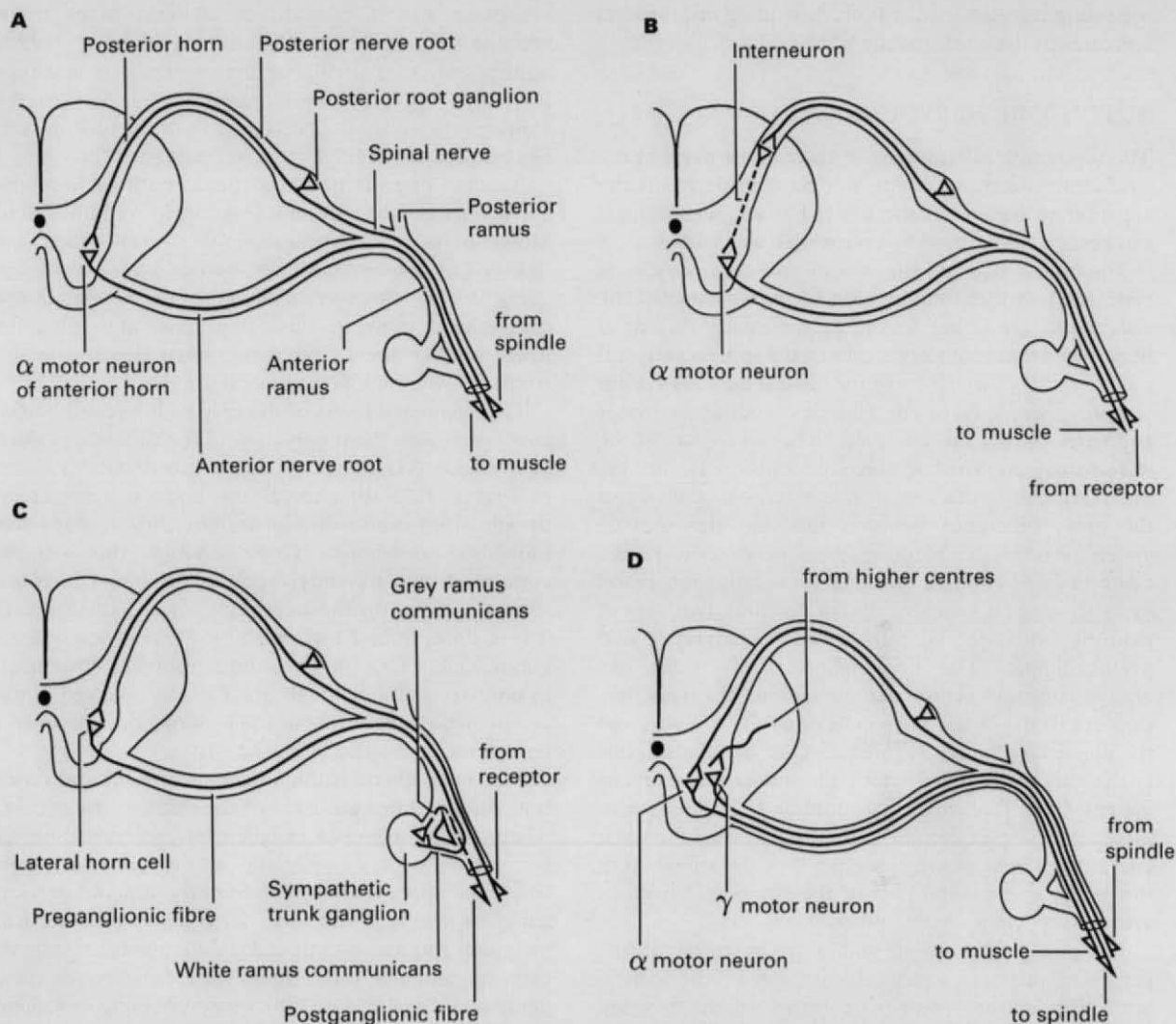


Fig. 1.20 Examples of spinal reflex pathways. **A** The two neurons of a stretch reflex (tendon jerk), which is monosynaptic. **B** A multisynaptic reflex arc; only one interneuron is shown but there may be several. **C** The three neurons of a sympathetic reflex, showing the different positions of cell bodies compared with **B**: that of the preganglionic cell in the lateral grey horn of the spinal cord (instead of the posterior horn), and that of the postganglionic cell in a sympathetic ganglion (instead of the anterior horn). Note that the sympathetic preganglionic fibre runs in the white ramus communicans (which is the more distal connexion of the ganglion) and the postganglionic fibre in the grey ramus. **D** The fusimotor neuron loop; the γ efferent neuron, under the influence of higher centres, stimulates the muscle spindle from which afferent fibres pass back to the spinal cord to synapse with the α motor neuron.

that in infants under 1 year old the extensor response is the normal response; only with myelination of the corticospinal tracts during the second year does the normal plantar reflex become flexor.

The **abdominal reflex** is elicited by lightly stroking across each quadrant of the anterior abdominal wall. Normally there is contraction of the underlying muscles, but the reflexes are absent in upper motor

neuron lesions. Patients with paraplegia who are lying down may exhibit *Beevor's sign*: when trying to lift the shoulders, the umbilicus is displaced upwards, due to weakness of the muscles below the umbilicus.

The **anal reflex** ('anal wink') is a visible contraction of the external anal sphincter following pinprick of the perianal skin, and the **bulbocavernosus reflex** is a contraction of this sphincter (palpable per rectum) on

squeezing the glans penis. Both depend on intact sacral segments of the cord (mainly S3).

AUTONOMIC NERVOUS SYSTEM

The topographical anatomy of the various parts of the autonomic nervous system will be considered in the appropriate regions of the body, but the system itself can best be understood by reviewing it as a whole.

The *motor* part of the *somatic* nervous system is concerned with the innervation of *skeletal muscle*. The cell bodies are either in the motor nuclei of cranial nerves or the anterior horn cells of the spinal cord, and the nerve fibres which leave the central nervous system run *uninterruptedly* to the muscles, ending as motor endplates on the muscle fibres. The *motor* part of the **autonomic nervous system** is concerned with the innervation of *cardiac and smooth muscle and glands*, and the great difference between this and the somatic system is that the pathway from nerve cells in the central nervous system to the target organ is *interrupted by synapses in a ganglion*. There are thus two sets of neurons which are logically called preganglionic and postganglionic. The preganglionic cell bodies are always within the central nervous system. If *sympathetic*, they are in the lateral horn cells of all the thoracic and the upper two lumbar segments of the spinal cord; this is the thoracolumbar part of the autonomic nervous system (the 'thoracolumbar outflow'). If *parasympathetic*, they are in certain cranial nerve nuclei and in lateral horn cells of sacral segments of the spinal cord; this is the craniosacral part of the autonomic nervous system (the 'craniosacral outflow').

The postganglionic cell bodies are in ganglia in the peripheral nervous system. If *sympathetic*, the ganglia are either in the sympathetic trunk, where they are collectively called *paravertebral ganglia*, or in certain other ganglia collectively called *collateral ganglia* (such as the coeliac ganglia). If *parasympathetic*, the ganglia are collectively called *terminal ganglia*; they are usually within the walls of the viscera concerned, or, in the case of certain head and neck structures, in four ganglia which are some little distance from the structures innervated.

Sympathetic nervous system

Having reached a sympathetic trunk ganglion, the incoming preganglionic fibres have one of three possible synaptic alternatives. The commonest is for them to synapse with cell bodies in a trunk ganglion — either in the one they entered (Fig. 1.22A), or to run up or down the trunk to some other trunk ganglion. The second alternative is to leave the trunk ganglion without

synapsing and to pass to a collateral ganglion for synapse (Fig. 1.22B). The third possibility (which applies only to a small number of fibres) is that they leave the trunk (without synapsing) to pass to the suprarenal gland, where certain cells of the medulla can be regarded as modified ganglion cells (p. 372).

Because there is no sympathetic outflow from the cervical part of the cord, nor from the lower lumbar and sacral parts, those preganglionic fibres which are destined to synapse with cell bodies whose fibres are going to run with cervical nerves must ascend in the sympathetic trunk to cervical ganglia, and those for lower lumbar and sacral nerves must descend in the trunk to lower lumbar and sacral ganglia.

The segmental levels of the preganglionic cell bodies concerned with the innervation of the different regions of the body (via postganglionic neurons) are indicated in Figure 1.23. In general the body is represented upright from head to perineum but with overlaps and individual variations. Thus although the neurons concerned with the innervation of the upper limb are shown as being in the lateral grey horns of segments T1–6, those from T1 segment mostly pass to postganglionic cells which innervate head and neck structures; in only 10% of individuals are T1 cells involved in the sympathetic supply to the upper limb, but the lowest level involved may be as low as T10.

The sympathetic trunk extends alongside the vertebral column from the base of the skull to the coccyx. Theoretically there is a ganglion for each spinal nerve, but fusion occurs, especially in the cervical region where the upper four unite to form the superior cervical ganglion, the fifth and sixth form the middle cervical ganglion, and the seventh and eighth fuse as the inferior cervical ganglion (and often with the first thoracic ganglion as well to form the cervicothoracic or stellate ganglion). Elsewhere there is usually one ganglion less than the number of nerves: 11 thoracic, 4 lumbar and 4 sacral.

The fibres from the lateral horn cells of each segment of the spinal cord leave in the anterior nerve root (with the axons of anterior horn cells) to reach the spinal nerve and its anterior ramus. The connecting links to the sympathetic trunk and its ganglia are the **rami communicantes**. There are normally two rami; the *white ramus communicans* is the more distal of the two (Fig. 1.21), and this is the one containing the preganglionic fibres (which are myelinated, hence called white). The other, the *grey ramus communicans*, contains efferent postganglionic fibres (which are unmyelinated, hence grey). The fibres in the grey ramus are those that are distributed via the branches of the spinal nerve to blood vessels, sweat glands and arrector pili muscles

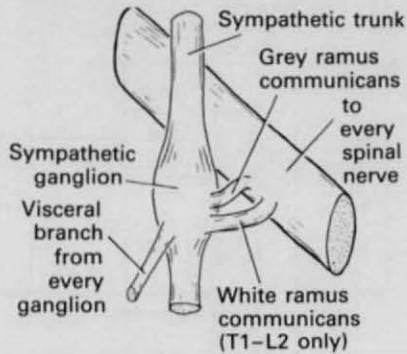


Fig. 1.21 Connexions of a typical sympathetic trunk ganglion. Every ganglion has a grey ramus and a visceral branch. Only those from T1 to L2 have a white ramus.

(i.e. they are vasomotor, sudomotor and pilomotor). Every spinal nerve receives a grey ramus. All the thoracic and the upper two lumbar nerves also give off white rami, but the cervical, lower lumbar and sacral nerves do not have white rami, because there is no sympathetic outflow from these segments of the cord. The ganglia with which these nerves are connected by their grey rami receive their preganglionic fibres from thoracolumbar lateral horn cells whose fibres after entering

the sympathetic trunk have run up or down in it (see above). Because of the fusion of ganglia, the superior cervical ganglion gives off four grey rami, and the other cervical ganglia two each. Occasional other rami (both grey and white) may be duplicated.

Each sympathetic trunk ganglion has a *collateral* or *visceral branch* (Fig. 1.21), usually called a *splanchnic nerve* in the thoracic, lumbar and sacral regions but in the cervical region called a *cardiac branch* because it proceeds to the cardiac plexus. The visceral branches generally arise high up and descend steeply to form plexuses for the viscera (Fig. 1.22). Thus cardiac branches arise from the three cervical ganglia to descend into the mediastinum to the *cardiac plexus*, which is supplemented by fibres from upper thoracic ganglia. From the lower thoracic ganglia the three splanchnic nerves pierce the diaphragm to reach the *coeliac plexus*, from the upper lumbar ganglia the lumbar splanchnic nerves descend to the *superior hypogastric plexus* and this divides to enter the left and right *inferior hypogastric plexuses*. The inferior hypogastric plexuses (collectively forming the *pelvic plexus*) are joined by visceral branches from all the sacral ganglia (sacral splanchnic nerves). (Do not confuse *sacral splanchnic nerves* which are sympathetic with *pelvic splanchnic nerves* which are parasympathetic — p. 33).

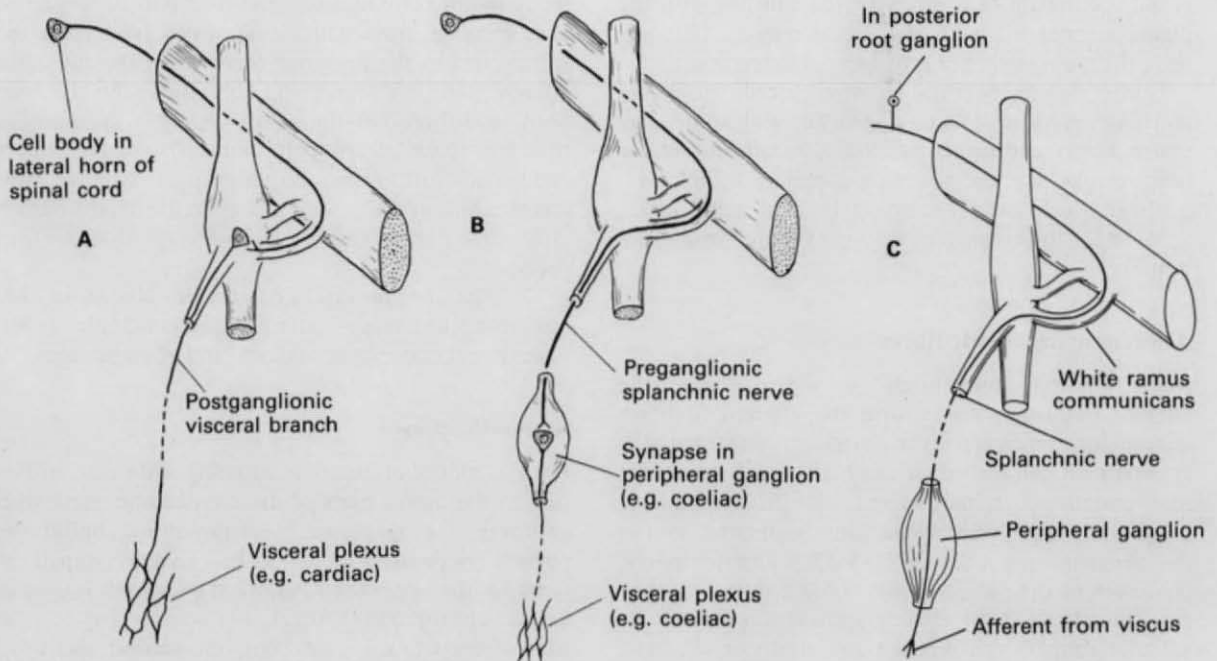


Fig. 1.22 Visceral connexions of sympathetic ganglia. **A** Efferent pathway with synapse in a sympathetic trunk ganglion. **B** Efferent pathway with synapse in a peripheral ganglion. **C** Afferent pathway for pain fibres, passing through the trunk ganglion and into the spinal nerve by the white rami communicans.

The sympathetic visceral plexuses thus formed are joined by parasympathetic nerves (vagus down to the coeliac plexus, pelvic splanchnics (S2, 3, 4) to the inferior hypogastric plexuses; see Figs 5.45, p. 365 and 5.63, p. 399). The mixed visceral plexuses reach the viscera by branches that hitch-hike along the relevant arteries.

In addition to the visceral branches, which supply not only the smooth muscle and glands of viscera but also the blood vessels of those viscera, all trunk ganglia give off *vascular branches* to adjacent large blood vessels. The cervical ganglia give branches to the carotid arteries and their branches, including (from the superior cervical ganglion) the internal carotid nerve(s), running upwards on the artery of that name to form the internal carotid plexus on the artery as it enters the skull. The thoracic and lumbar ganglia give filaments to the various parts of the aortic plexus and its derivatives, including those along the common iliac and median sacral arteries, and branches from the sacral ganglia pass to the lateral and median sacral arteries. Note that although the head and neck arteries receive direct branches from cervical trunk ganglia, *limb vessels* get their sympathetic innervation by nerve fibres that run with the adjacent peripheral nerves before passing to the vessels; the fibres do not run long distances along the vessels themselves. Thus the nerve filaments to the vessels of the tip of a finger or toe run not with the digital arteries but with the digital nerves, and only leave the nerves near the actual site of innervation.

During development not all ganglion cells succeed in reaching trunk or collateral ganglia, and some may unexpectedly end up as *intraneural ganglia* in various nerve trunks (e.g. the accessory ganglion in Fig. 5.44, p. 364). Such ganglia may, at least in some cases, account for the anomalous results of some sympathectomies.

Afferent sympathetic fibres

Many afferent fibres hitch-hike along sympathetic efferent pathways. Some form the afferent limb for unconscious reflex activities; others are concerned with visceral pain. All have their cell bodies in the posterior root ganglia of spinal nerves (not in sympathetic ganglia), at approximately the same segmental level as the preganglionic cells (Fig. 1.23). The peripheral processes of the sensory cells, coming from whatever structure received the efferent innervation (usually its vascular supply), run through any plexus or collateral ganglion with which the efferent fibres were involved, and then enter the sympathetic trunk (Fig. 1.22C). From there the fibres reach the spinal nerve via the

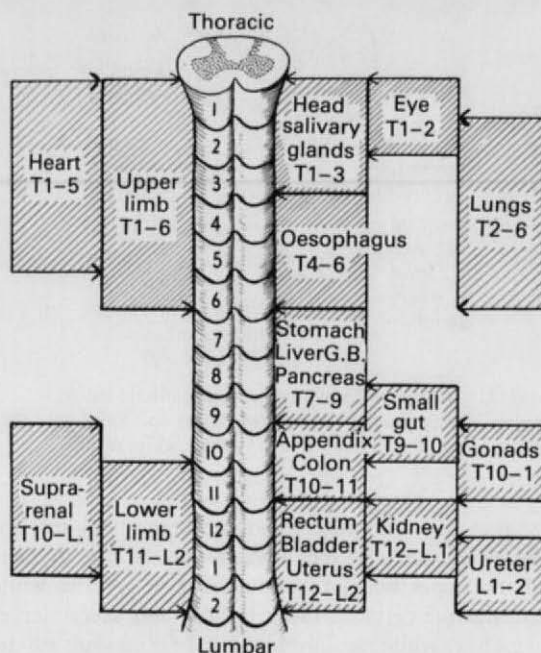


Fig. 1.23 Spinal levels of sympathetic preganglionic cells. There may be considerable individual variations, especially for the upper limb. See text for explanation.

white ramus communicans and then join the posterior root ganglion, from which central processes enter the spinal cord by the posterior nerve root (like any other afferent fibres). Visceral pain fibres enter the posterior horn, and thereafter the pain pathway is the same as that for spinal nerve pain fibres (p. 624). Others concerned with reflex activities may synapse with interneurons in the cord or ascend to the hypothalamus and other higher centres by pathways that are not defined.

Note that the grey ramus communicans contains only one group of fibres — efferent postganglionic — but white rami contain preganglionic and afferent fibres.

Sympathectomy

For the control of excessive sweating and vasoconstriction in the limbs, parts of the sympathetic trunk with appropriate ganglia can be removed to abolish the normal sympathetic influence. In 'cervical' sympathectomy for the upper limb (so called because it is usually carried out through the neck, not because any cervical part of the trunk is removed), the second and third thoracic ganglia with their rami and the intervening part of the trunk are resected. The first thoracic ganglion is not removed, since the preganglionic fibres for the

upper limb do not usually arise above T2 level (see above), and its removal would result in Horner's syndrome (p. 519). Cervical sympathectomy is described on page 280.

For lumbar sympathectomy the third and fourth lumbar ganglia and the intervening trunk are removed; preganglionic fibres do not arise below L2 level. The first lumbar ganglion should be preserved otherwise ejaculation may be compromised; the exact positions of the ganglia vary, and they have no constant relation to the lumbar vertebrae. Lumbar sympathectomy is described on page 365.

PARASYMPATHETIC NERVOUS SYSTEM

Although all parts of the body receive a sympathetic supply, the distribution of parasympathetic fibres is wholly visceral and not to the trunk or limbs. However, not all viscera are so innervated; the suprarenal glands and the gonads appear to have only a sympathetic supply.

The preganglionic fibres of cranial origin (see below) have their cell bodies either in the accessory (Edinger–Westphal) oculomotor nucleus, the superior and inferior salivary nuclei, or the dorsal motor nucleus of the vagus. The postganglionic cells for the first three of the above groups are in the four parasympathetic ganglia, discussed below. The vagal fibres synapse with postganglionic cell bodies in the walls of the viscera supplied (heart, lungs and gut).

The preganglionic fibres of sacral origin arise from cells in the lateral grey horn of sacral segments 2–4 of the spinal cord, and constitute the **pelvic splanchnic nerves**. Leaving the anterior rami of the appropriate sacral nerves near the anterior sacral foramina they pass forwards to enter into the formation of the inferior hypogastric plexuses (pelvic plexus). From there they run to pelvic viscera and to the hindgut as far up as the splenic flexure. Fibres reach the viscera either by running along their blood vessels or making their own way retroperitoneally, and they synapse around postganglionic cell bodies in the walls of these viscera.

Cranial parasympathetic ganglia

The four ganglia — ciliary, pterygopalatine, submandibular and otic — are very similar in plan. Each has parasympathetic, sympathetic and sensory roots, and branches of distribution (Fig. 1.24). The roots and branches are described in general terms below; the topographical details of each ganglion are dealt with in the regions concerned, but a summary of

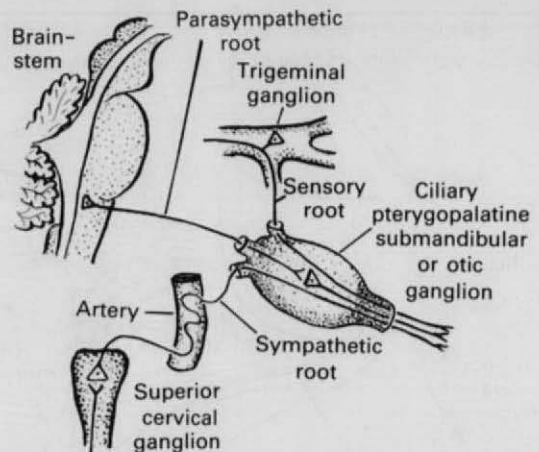


Fig. 1.24 Plan of connexions of cranial parasympathetic ganglia. Only the parasympathetic root relays in the ganglion.

their connexions is given here (for reference rather than memorizing at this stage) and illustrated in Figure 1.25.

The *parasympathetic root* carries the preganglionic fibres from the cells of origin in a brainstem nucleus. This is the essential functional root of the ganglion; its fibres synapse in it, whereas the fibres of all other roots simply pass through the ganglion without synapse. (This parasympathetic root is sometimes called the 'motor' root, but the sympathetic fibres are of course also 'motor' in their own way.)

The *sympathetic root* contains postganglionic fibres from the superior cervical ganglion, whose preganglionic cell bodies are in the lateral grey horn of cord segments T1–3.

The *sensory root* contains the peripheral processes of cell bodies in the trigeminal ganglion.

The *branches* of each ganglion carry the postganglionic parasympathetic fibres to the particular structure(s) requiring this kind of localized motor innervation: ciliary muscle and sphincter pupillae from the ciliary ganglion, salivary glands from the submandibular and otic ganglia, and lacrimal, nasal and palatal glands from the pterygopalatine ganglion. The other fibres in the branches contribute sympathetic fibres to the same structures (mainly for their blood vessels) and also carry afferent fibres.

Ciliary ganglion (p. 513)

Parasympathetic root. From the Edinger–Westphal part of the oculomotor nucleus by a branch from the nerve to the inferior oblique muscle (from the inferior division of the oculomotor nerve).

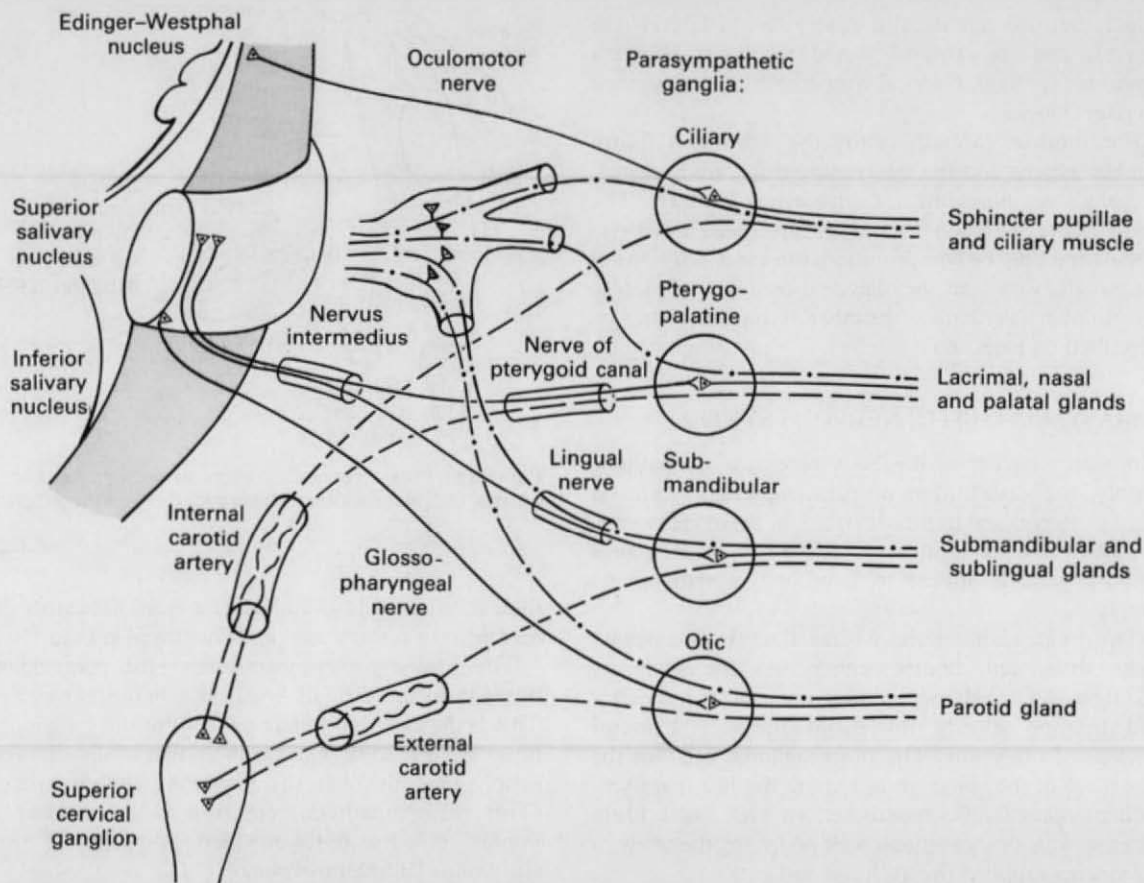


Fig. 1.25 Connexions of the four parasympathetic ganglia of the head and neck.

Sympathetic root. From the superior cervical ganglion by branches of the internal carotid nerve.

Sensory root. From a branch of the nasociliary nerve, with cell bodies in the trigeminal ganglion.

Branches. Short ciliary nerves to the eye.

Pterygopalatine ganglion (p. 467)

Parasympathetic root. From the superior salivary nucleus by the nerve of the pterygoid canal and the greater petrosal nerve from the nervus intermedius part of the facial nerve.

Sympathetic root. From the superior cervical ganglion by the internal carotid nerve, the deep petrosal nerve and the nerve of the pterygoid canal.

Sensory root. From a branch of the maxillary nerve, with cell bodies in the trigeminal ganglion.

Branches. To the lacrimal gland via the zygomatic and lacrimal nerves, and to mucous glands in the nose,

nasopharynx and palate via maxillary nerve branches. A few fibres (not shown in Fig. 1.25) are taste fibres from the palate, running in the greater petrosal nerve with cell bodies in the geniculate ganglion of the facial nerve.

Submandibular ganglion (p. 485)

Parasympathetic root. From the superior salivary nucleus by the nervus intermedius part of the facial nerve and the chorda tympani, joining the lingual nerve.

Sympathetic root. From the superior cervical ganglion by fibres running with the facial artery.

Sensory root. From a branch of the lingual nerve, with cell bodies in the trigeminal ganglion.

Branches. To the submandibular and sublingual glands via branches of the lingual nerve.

Otic ganglion (p. 362)

Parasympathetic root. From the inferior salivary nucleus by the glossopharyngeal nerve and its tympanic branch to the tympanic plexus and then to the lesser petrosal nerve.

Sympathetic root. From the superior cervical ganglion by fibres running with the middle meningeal artery.

Sensory root. From the auriculotemporal nerve with cell bodies in the trigeminal ganglion.

Branches. To the parotid gland via filaments of the auriculotemporal nerve.

Unlike the other three ganglia, the otic ganglion has an additional *somatic motor root*, from the nerve to the medial pterygoid; the fibres pass through (without synapse) to supply tensor tympani and tensor palati.

Parasympathetic afferent fibres

As in the sympathetic nervous system, afferent fibres often accompany the parasympathetic supply to various structures. Such fibres that run with the glossopharyngeal and vagus nerves have their cell bodies in the inferior ganglia of those nerves, and their central processes pass to the nucleus of the tractus solitarius, through which there are connexions with other parts of the brainstem and higher centres for the reflex control of respiration, heart rate, blood pressure, gastrointestinal activity, etc.

The pelvic splanchnic nerves also carry afferent fibres. Their cell bodies are in the posterior root ganglia of the second to fourth sacral nerves and the central processes enter the cord by the posterior nerve roots. Some make local synaptic connexions, e.g. for bladder reflexes, but others are pain fibres from pelvic viscera, which often seem to use both sympathetic and parasympathetic pathways for pain transmission, e.g. bladder and rectum.

PART 3**EARLY EMBRYOLOGY**

The development of most of the organs and systems is touched upon in the text descriptions of the regions concerned. Here a very brief account of some important features of early development is included, simply to provide a background for the later notes, which are also brief; those who need further details must consult specialist texts.

Early development

For the first 8 weeks of the 40-week human gestation period the developing organism is an **embryo**; after that time it is a **fetus**. By the end of the embryonic period most organs have differentiated, and the changes during the fetal period are essentially those of maturation. Many but not all congenital defects are initiated in the embryo rather than the fetus.

The fertilized ovum or **zygote** undergoes repeated cell divisions (cleavage) to produce a mass of cells, the **morula**, which travels along the uterine tube towards the uterus. Further division enlarges the morula and a fluid-filled cavity (the extraembryonic coelom) appears in it; the whole structure is now a **blastocyst**. At this stage implantation into the uterine mucosa takes place, about 6 days after fertilization. The outer layer of cells in the blastocyst, the **trophoblast**, is destined to become placental. The remainder of the cells are concentrated at one end of the blastocyst to form the **inner cell mass**, attached to the inner layer of the trophoblast. Within this inner cell mass a further two cavities appear, **amnion** and **yolk sac** respectively (Fig. 1.26). These two bubbles within the original bubble are separated by a mass of cells, the **embryonic plate**, from which the tissues and organs of the embryo will differentiate. On the amniotic aspect of the embryonic plate is **ectoderm**, on the yolk sac aspect is **endoderm**. Between them is **primary mesoderm**, later to be added to by the appearance of so-called secondary mesoderm, derived from cells of the ectoderm. An axial rod of cells grows in from the ectoderm towards the endoderm; this is the **notochord**, and alongside it the embryo now possesses bilateral symmetry. On the dorsal (ectodermal, amniotic) surface of the embryonic plate the neural groove develops. Its edges unite to form the **neural tube**, which becomes depressed below the surface and from which the brain and spinal cord develop. Some of the cells derived from the edges of the

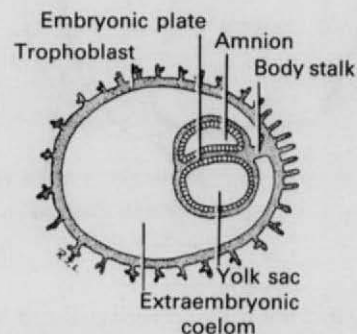


Fig. 1.26 Longitudinal section through an early embryo.

groove become isolated between the tube and the overlying ectoderm to form the **neural crest**. Its cells are destined to migrate to develop into a number of structures, in particular the posterior root ganglia of spinal nerves, the corresponding ganglia of cranial nerves, autonomic ganglia, the satellite cells of ganglia and the Schwann cells of peripheral nerves, and the chromaffin cells of the suprarenal medulla.

Alongside the notochord and neural tube the mesoderm lies in three longitudinal strips. That nearest the midline is the **paraxial mesoderm**; it becomes segmented into masses of cells called mesodermal **somites** (Fig. 1.27). The somites produce: (1) the *sclerotome*, medially, which surrounds the neural tube and notochord, producing the vertebrae and dura mater, and (2) the *myotome* or muscle plate, laterally, which produces the muscles of the body wall.

The intermediate strip of mesoderm is the **intermediate cell mass** and becomes segmented. It projects ventrally between the other two strips (Fig. 1.28). From its *lateral* side in craniocaudal sequence develop successively the pronephros, mesonephros and metanephros and their associated ducts — the progenitors of the urinary and genital systems. Its *medial* side gives rise to the gonad and the cortex of the suprarenal gland. The most lateral strip of mesoderm is the **lateral plate** and is unsegmented (Fig. 1.27).

Very early the embryo begins to curl up, a result of

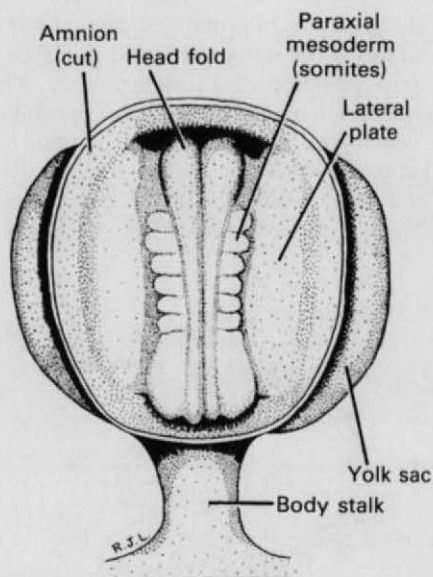


Fig. 1.27 Dorsal view of the amniotic plate after removal of amnion (after Keith). At a slightly later stage a ventral view of this embryo would resemble Figure 1.37A.

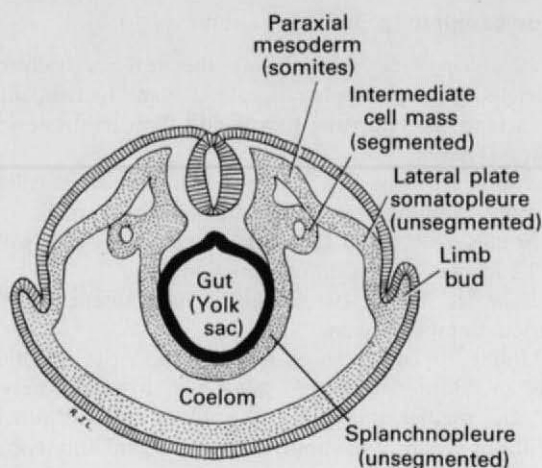


Fig. 1.28 Cross-section through an embryo similar to that illustrated in Figure 1.27 but at a slightly later stage.

the more rapid growth of the dorsal (ectodermal) surface. The embryo becomes markedly convex towards the amnion and correspondingly concave towards the yolk sac. As the lateral plate curls around to enclose the yolk sac its mesoderm becomes split into two layers by a space that appears within it. The space is the beginning of the intraembryonic **coelom** or body cavity. The inner layer is the **splanchnopleure**; it is innervated by the autonomic nervous system. It encloses the yolk sac in an hourglass constriction; the part of the yolk sac outside persists in the umbilical cord as the vitellointestinal duct, the part inside the embryo becomes the alimentary canal. The outer layer of the lateral plate is the **somatopleure**; it is innervated by the somatic (spinal) nervous system. Into it the paraxial myotomes migrate in segments to produce the flexor and extensor muscle layers of the body wall. The coelomic cavity at first includes pleura and peritoneum in one continuum; they become separated later. The lining of the cavity is mesodermal; note that the parietal layer of these serous membranes is supplied by somatic nerves, while the visceral layer is innervated, if at all, by autonomic nerves.

The **limb buds** grow from the lateral plate mesoderm and their muscles develop in situ. Although the lateral plate mesoderm is unsegmented the motor fibres that grow into it from the spinal cord limb plexuses arrange their distribution in a very definite segmental pattern (p. 21).

The **septum transversum** consists of the mass of mesoderm lying on the cranial aspect of the coelomic cavity. Its cranial part contains the pericardial cavity, the walls of which develop into the pericardial

membranes and part of the diaphragm (p. 251). It is invaded by muscles from cervical myotomes, mainly the fourth; they produce the muscle of the diaphragm. The caudal part of the septum transversum is invaded by the developing liver, which it surrounds as the ventral mesogastrium. The septum transversum later descends, taking the heart with it, to the final position of the diaphragm.

The folding of the embryo is impeded to some extent at the tail end by the presence of the **body stalk**, which later becomes the *umbilical cord*. The greatest amount of folding occurs at the head end of the embryo (Fig. 1.13). By the end of the first fortnight the forebrain capsule is folded down over the pericardium and a mouth pit, the **stomodeum**, shows as a dimple between the two. Within the body of the embryo the gut cavity extends headwards dorsal to the pericardium, as far forwards as the *buccopharyngeal membrane*, which closes the bottom of the mouth pit. The buccopharyngeal membrane breaks down and disappears so early (third week) that its former site cannot be made out with certainty in the later embryo or adult. Cranial to the site of the membrane the mouth pit is lined with ectoderm; this includes the region of all the mandibular and maxillary teeth, and probably the submandibular and sublingual glands, and perhaps even the anterior two-thirds of the tongue. *Rathke's pouch* arises from this ectoderm and forms the anterior lobe of the pituitary gland. Caudal to the buccopharyngeal membrane is the pharynx, lined with endoderm and lying dorsal to the pericardium.

BRANCHIAL ARCHES AND POUCHES

Mesodermal condensations develop in the side walls of the primitive pharynx to form the **branchial arches** and they grow around towards each other ventrally, where they fuse in the midline. In this way a series of horseshoe-shaped arches (often called pharyngeal arches) comes to support the pharynx (Fig. 1.29). The most cranial arch, the mandibular, separates the mouth pit from the pericardium; as the latter moves caudally by a process of differential growth in the neck the floor of the pharynx elongates and comes successively to possess six of these arches, separated from each other at the side of the pharynx by the pharyngeal or **branchial pouches** (the name given to the *internal* grooves between the arches; the *external* grooves are the **branchial clefts**, Fig. 1.29). The fourth and fifth pouches open into the pharynx by a common groove on each side; thus there are but four pouches separating the six arches (Fig. 1.29). On the external aspect of the pharynx four ectodermal depressions correspond in

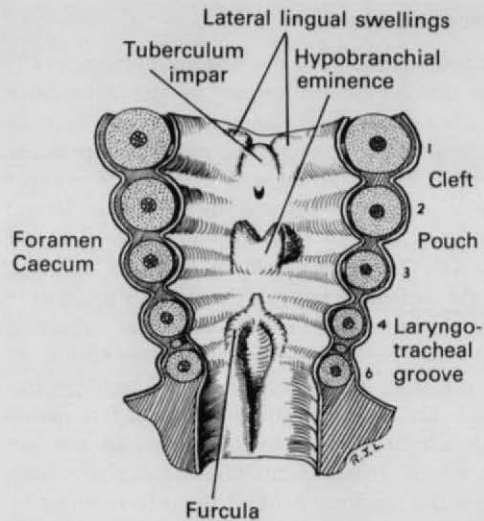


Fig. 1.29 Floor of the developing pharynx. The pharyngeal (branchial) arches are numbered. The foramen caecum lies in the midline between the first and second arches.

position with the four endodermal depressions within. The four thin parts, between the arches, break down in fishes to form the gill slits or gill clefts; in mammals, however, the ectoderm and endoderm not only remain intact but are actually separated by mesoderm. The mammalian arches and pouches are taken to be homologous with the gill apparatus of fish. It clarifies the understanding of much of the anatomy of the neck to consider the derivatives of the arches and of the pouches, and the midline structures derived from the floor of the primitive pharynx.

In man the fate of the arches is known in greater detail at the cranial end of the pharynx and as we proceed caudally our knowledge becomes less precise. In general it may be stated that the first arch develops into the mandible and maxilla, the second into part of the hyoid bone, the third into the remainder of the hyoid bone, and the fourth, fifth and sixth into the cartilages of the larynx. In each arch a central bar of *cartilage* forms and *muscle* differentiates from the mesoderm around it. An artery and cranial nerve are allocated to the supply of each arch and its derivatives. Vascular patterns are very changeable during development, but a nerve supply, once established, remains constant. Outgrowths from the intervening pouches, mostly glandular, are supplied by the artery and nerve of the arch nearest to their place of origin.

The derivatives of the first arch require more detailed explanation than those of the remainder, which can be noted in summary form.

First (mandibular) arch

The right and left halves of the first arch fuse ventrally in the midline. Chondrification in the mesoderm produces *Meckel's cartilage*. Cranially a bump appears on each side of the arch; this is the **maxillary process** (not derived from the cartilage). The two grow towards the midline, meet each other and the medial and lateral nasal processes, and so produce the upper jaw and palate (p. 41). The dorsal end of Meckel's cartilage produces the *incus* and *malleus*, the *anterior ligament of the malleus* and the *sphenomandibular ligament* (Fig. 1.30). The latter is the fibrous perichondrium of Meckel's cartilage, remaining after the cartilage has disappeared. The *lingula* at the mandibular foramen is a small persistent part of the cartilage; so too are the chin bones (*ossa mentalia*) occasionally seen persisting at the midline. Around the intervening part of Meckel's cartilage the mandible, ossifying in membrane at the sixth week, extends in two symmetrical halves. Some time after birth the cartilage disappears.

Ectodermal and endodermal derivatives of this arch are the mucous membrane and glands (but not the muscle) of the anterior two-thirds of the tongue, mesodermal derivatives are the muscles of mastication (masseter, temporal and pterygoids), the mylohyoid and anterior belly of digastric, and the two tensor muscles (tensor palati and tensor tympani) — in a word, all the muscles supplied by the **mandibular nerve**, which also has sensory fibres. But the taste buds of the anterior part of the tongue are supplied by the chorda tympani branch of the facial nerve, which is the nerve of the second arch (see below). How does this come about? The answer is derived from studies of comparative anatomy. The chorda tympani is regarded as the 'pretrematic' branch of the second arch nerve. The word *trema* means a cleft, and the

sensory nerves of branchial arches (in those vertebrates that have gill clefts) divide to supply tissue in front of and behind each arch, i.e. they divide into pretrematic and post-trematic branches. Thus the chorda tympani, the pretrematic branch of the second arch nerve, supplies some sensory fibres to the first arch, and is generally recognized as the human counterpart of a more primitive vertebrate pattern. The artery is the first aortic arch, part of which persists as the maxillary artery (Fig. 1.36). Note that the first arch, often called **mandibular**, gives origin to the *maxillary process*, and this has its own sensory nerve, the maxillary branch of the trigeminal.

Other arches

The skeletal and muscular derivatives of the remaining arches can be summarized as follows:

Second (hyoid) arch

Skeletal derivatives: stapes, styloid process, stylohyoid ligament, lesser horn and upper part of body of hyoid bone (Fig. 1.31).

Muscular derivatives: muscles of facial expression (including buccinator and platysma), stapedius, stylohyoid, posterior belly of digastric — all supplied by the facial, the nerve of the second arch.

Third arch

Skeletal derivatives: greater horn and caudal part of body of hyoid bone (Fig. 1.31).

Muscular derivatives: stylopharyngeus — supplied by the glossopharyngeal, the nerve of the third arch.

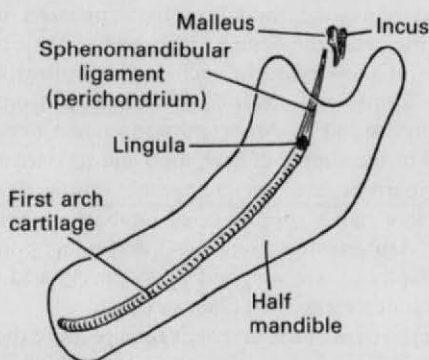


Fig. 1.30 Derivatives of the first arch cartilage.

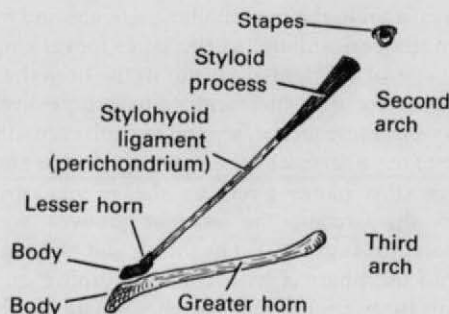


Fig. 1.31 Derivatives of the second and third arch cartilages.

Fourth and sixth arches

Skeletal derivatives: thyroid, cricoid, epiglottic and arytenoid cartilages.

Muscular derivatives: intrinsic muscles of larynx, muscles of pharynx, levator palati — all supplied by laryngeal and pharyngeal branches of the vagus, the nerve of these arches.

Lateral derivatives of the branchial pouches

Except for the first, each pouch grows laterally into a dorsal and a ventral diverticulum.

First pouch. This is the only pouch in which ectoderm and endoderm remain in close apposition, namely at the tympanic membrane, where the mesoderm separating them is minimal. In the other pouches the ectoderm and endoderm are finally widely separated. The endoderm of the first pouch is prolonged laterally, via the auditory tube, to form the middle ear and mastoid antrum (the second pouch gives a contribution to the middle ear — see below). The (external) branchial groove becomes deepened to form the external acoustic meatus.

Second pouch. The *dorsal diverticulum* assists the first pouch in the formation of the tympanic cavity, taking what may be its pretrematic nerve (the tympanic branch of the glossopharyngeal) with it. The *ventral diverticulum* of the pouch develops the tonsillar crypts and the supratonsillar fossa from its endoderm, the surrounding mesoderm contributing the lymphatic tissue of the palatine tonsil. The nerve supply of these derivatives is the glossopharyngeal, overlapped in part by the facial.

Third pouch. *Dorsally* the inferior parathyroid gland (often called parathyroid III) and *ventrally* the thymic rudiment grow from this pouch. The latter progresses caudally and joins with that of the other side to produce the bilobed thymus gland. In its descent the thymic bud draws parathyroid III in a caudal direction, so that ultimately the latter lies inferior to parathyroid IV, which is derived from the fourth pouch. Externally the cervical sinus overlies the pouch and it is probable that some of the thymic rudiment is derived from the ectoderm thereof. From this thymic bud the medulla of the thymic lobule, including the thymic (Hassall's) corpuscles, is derived; the lymphocytes of the cortex originally migrated from bone marrow.

Fourth pouch. *Dorsally* the superior parathyroid glands (parathyroid IV) are derived from the endodermal lining of this pouch. *Ventrally* the pouch is attached to the thyroid gland, thus preventing parathy-

roid IV (the superior parathyroid of the adult) from descending, and probably makes a contribution to the thymus.

Fifth pouch. This undergoes regression and is now considered to form the *ultimobranchial body*, from which are derived the parafollicular (C) cells of the thyroid gland which produce calcitonin.

Cervical sinus

Concurrently with the growth of the above derivatives from the endoderm of the pouches a change takes place externally in the overlying ectoderm. The second arch increases in thickness and grows caudally, covering in the third, fourth and sixth arches and meeting skin caudally to these. Thus a deep groove is formed, which becomes a deep pit, the **cervical sinus**. The lips of the pit meet and fuse and the imprisoned ectoderm disappears. Persistence of this ectoderm gives rise to a *branchial cyst*. A *branchial fistula* sometimes results from breaking down of the endoderm in, usually, the second pouch; the track then runs from the region of the tonsil, between the external and internal carotid arteries (Fig. 1.36), and reaches the skin anterior to the lower end of sternocleidomastoid.

It is this formation of the cervical sinus and subsequent obliteration of ectoderm that joins skin over the mandible (mandibular branch of the trigeminal) to neck skin (C2). The ectoderm supplied by the facial, glossopharyngeal and vagus nerves and C1 lines the cervical sinus.

Ventral derivatives of the floor of the pharynx

From the floor of the mouth and pharynx are derived the tongue, thyroid gland and larynx (Fig. 1.29).

Buds from the first, third and fourth arches form the epithelium and glands of the tongue, with occipital myotomes providing the musculature (p. 484).

The **thyroglossal duct** evaginates from the foramen caecum ventrally between the first and second arches and then passes caudally in front of the remaining arches. The thyroid gland buds from the duct's distal end (p. 432), which itself may give rise to the pyramidal lobe. Other remnants of the duct may persist and give rise to cysts, commonly behind the body of the hyoid bone; the duct is kinked by the hyoid bone growing downwards (Fig. 1.32). Rarely the duct may pass behind or even through the bone.

In the ventral wall of the oesophagus a **laryngo-tracheal groove** appears. The cephalic end of this gutter is limited by the *furcula*, a ridge in the shape of a wish-

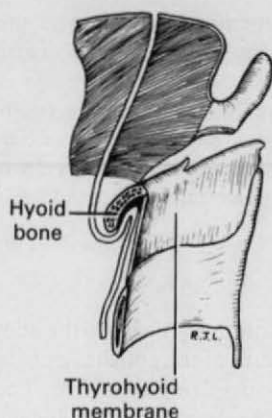


Fig. 1.32 Course of the thyroglossal duct. If a remnant persists it usually does so at the kink behind the body of the hyoid bone.

bone which lies in the caudal part of the floor of the pharynx (Fig. 1.29). The ridges which limit the gutter grow towards each other and, by their fusion, convert the gutter into a tube. This tube, the *trachea*, then separates from the *oesophagus* and buds out into the *bronchi* and *lungs* at its caudal end. The process of fusion does not, of course, affect the *furcula*, which persists at the aperture of the larynx whose cartilages, including that of the epiglottis, derive from the underlying fourth and sixth pharyngeal arches.

Branchial arch arteries

From the cephalic end of the primitive heart tube (p. 44) a *ventral aorta* divides right and left into two branches which curve back caudally as the two *dorsal aortae* which are essentially continued into the two *umbilical arteries*. As the branchial arches develop a vessel in each arch joins the ventral to the dorsal aortae. Thus six aortic arches are to be accounted for (Fig. 1.33–1.36).

The first and second arch arteries disappear early, their only remnants in the adult being the maxillary and stapelial arteries respectively. The fifth disappears entirely. The third remains as part of the internal carotid artery. The fourth on the right persists as the subclavian artery, on the left as the arch of the aorta. By the time the sixth artery appears the upper bulbar part of the heart tube has been divided into aorta and pulmonary trunk (p. 276). It is to the pulmonary trunk that the sixth arch arteries are connected ventrally (Fig. 1.34). Dorsally they communicate with the dorsal aortae. The pulmonary arteries grow out from the sixth arch. The dorsal part of the sixth arch

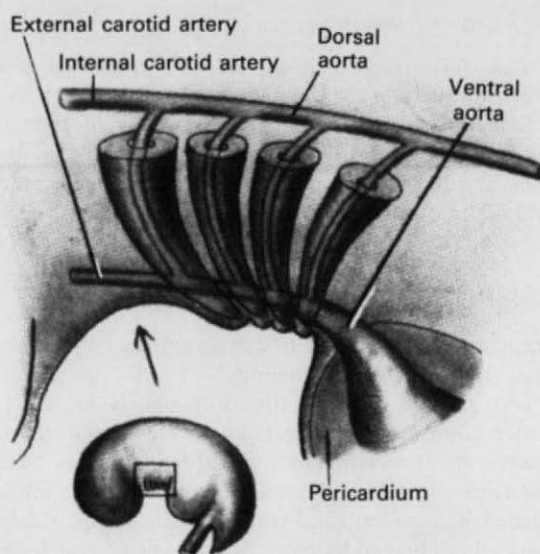


Fig. 1.33 Arteries of the first four pharyngeal arches viewed from the left (an enlargement of the rectangular area shown in the small figure). The arrow points to the stomodeum. Each arch has an artery which passes from the ventral to the dorsal aorta of its own side.

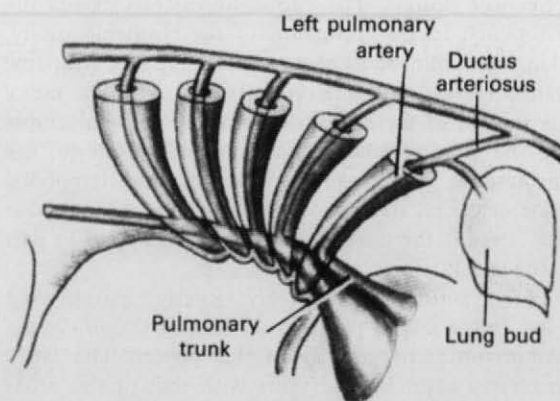


Fig. 1.34 Origin of the sixth arch arteries from the pulmonary trunk. The artery gives a branch to the lung bud but most of its blood is short-circuited to the dorsal aorta by the ductus arteriosus.

artery disappears on the right side but persists on the left as the ductus arteriosus which thus connects the left pulmonary artery to the arch of the aorta (Fig. 1.35).

Anomalies of the great vessels

The commonest anomaly of development is a *patent ductus arteriosus* (persistence of part of the left sixth

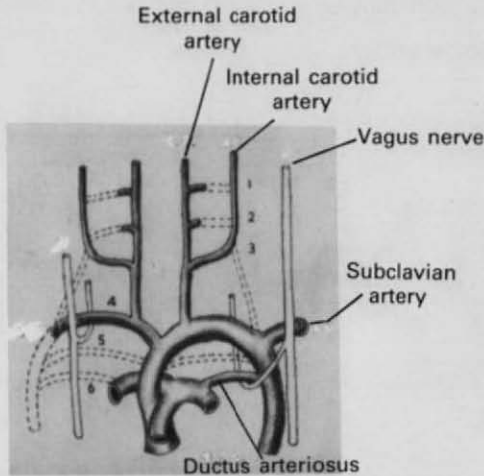


Fig. 1.35 Fate of the arch arteries. The arteries are numbered and the dotted lines indicate the arteries that disappear. The embryological symmetry of the recurrent laryngeal nerves is replaced by final asymmetry: the left hooks round the ductus arteriosus but the right hooks round the right subclavian artery.

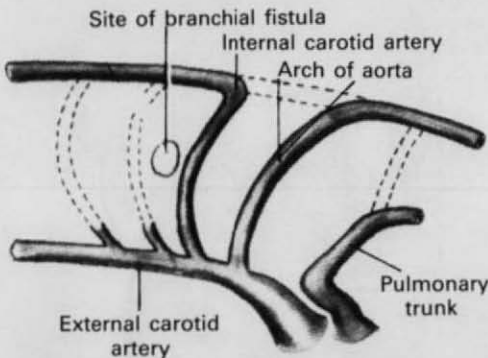


Fig. 1.36 Site of a branchial fistula, due to the breakdown of (usually) the second pharyngeal pouch, with the opening in the pharynx above the tonsil. The arteries are viewed from the left as in Figure 1.34, and the dotted lines indicate arteries that disappear. The fistula lies between the external and internal carotid arteries. (Sternocleidomastoid is always behind it, since the muscle migrates from a dorsal site.)

arch), which fails to close in the immediate postnatal period. *Coarctation* of the aorta (narrowing) is due to a defect of the tunica media which forms a shelf-like projection into the lumen, most commonly in the region of the ductus; collateral circulation distal to the obstruction is provided by the internal thoracic and posterior intercostal arteries. An *abnormal origin of the right subclavian artery* (just distal to the origin of the left

one) occurs when the right fourth aortic arch disappears and the distal part of the right dorsal aorta persists. The artery passes behind the oesophagus and is a possible cause of dysphagia, but may be more important surgically because, with the lack of a normal right subclavian arch, the right recurrent laryngeal nerve is *not recurrent* and runs down the side of the larynx — a possible hazard in thyroidectomy. The reported incidence varies from 1–2%.

Several kinds of uncommon defect occur when arches persist instead of becoming obliterated or vice versa (refer to the normal pattern seen in Fig. 1.35). A *right aortic arch* occurs when the left fourth arch and dorsal aorta disappear. If the left fourth arch alone (and not the dorsal aorta as well) disappears, the condition of *interrupted arch* arises; the first part of the arch gives off the brachiocephalic and left common carotid vessels, and beyond the gap the pulmonary trunk and a persistent patent ductus (sixth arch) are required to complete an 'arch' with the left dorsal aorta. If the right dorsal aorta persists as well as the left, a *double arch* ensues with the trachea and oesophagus clasped between the two.

DEVELOPMENT OF MOUTH AND FACE

The stomodeum is present at the third week, when somites appear and the buccopharyngeal membrane breaks down. The frontonasal process and the beginning of mandibular and hyoid arches appear in the fourth week, when the embryo is 3 mm long. The teeth begin as the dental lamina at the sixth week, when the embryo is 12 mm long. Calcification of the first dentine, soon followed by the enamel, begins in the fifth month.

The stomodeum is bounded by the mandibular arch, which produces the floor of the mouth, lower jaw and lower lip, and the two maxillary processes. Its cranial boundary is the forebrain capsule (Fig. 1.37A), from which the frontonasal process grows. The **frontonasal process** is indented by two **nasal pits**, which divide it into a **median** and two **lateral nasal processes**. The median process is characterized by a pair of convex **globular processes** (Fig. 1.37B). The lateral nasal processes unite with them to encircle the nostril. The maxillary and lateral nasal processes encircle the eye and meet together along the line of the nasolacrimal duct (Fig. 1.37C). The maxillary processes in man unite in the midline below the nostril to produce the *whole of the upper lip* and the maxillae (Fig. 1.37D). The frontonasal process produces the premaxilla, which emerges on the facial skeleton in lower animals but is

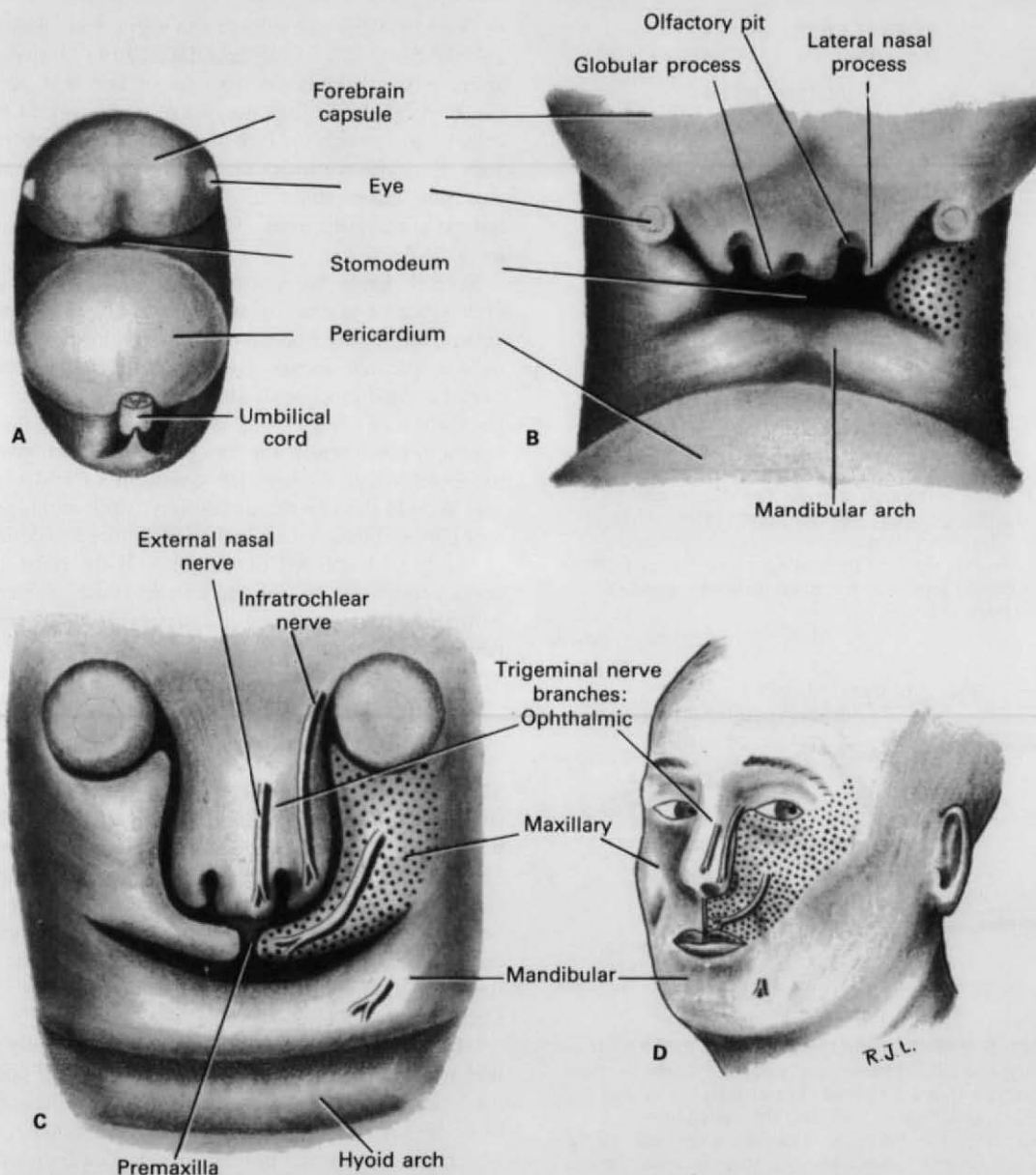


Fig. 1.37 Stages in the development of the face. **A** Ventral view of an early embryo after the formation of the head fold. The slit-like stomodeum appears between the forebrain capsule and the pericardium. **B** Ventral view of the stomodeum at the next stage. From the forebrain capsule the frontonasal process grows down, divided by a pair of olfactory pits into a median and two lateral nasal processes. The median nasal process is divided by a midline pit into two globular processes. The stomodeum is separated from the pericardium by the mandibular arch, from each side of which grows a maxillary process (the left one is stippled in **B**, **C** and **D**). **C** The median nasal process forms the tip of the nose (supplied by the external nasal nerve). The lateral nasal process forms the ala of the nose (supplied by the infratrochlear nerve). The maxillary processes (supplied by the maxillary nerve) grow together across the premaxilla. (*Diagrammatic*: no actual clefts exist in the human embryo.) **D** Final result. The whole of the upper lip, including the philtrum, is derived in man from the maxillary processes. The derivatives of the frontonasal process are supplied by the ophthalmic nerve (upper branch of the trigeminal), those of the maxillary process by the maxillary nerve (middle branch of the trigeminal), and those of the mandibular arch by the mandibular nerve (lowest branch of the trigeminal).

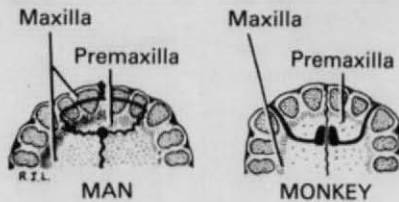


Fig. 1.38 Hard palates of man and monkey compared. In man the maxillae meet across the premaxilla. In the monkey the premaxilla lies on the face.

covered over by medial extensions of the maxilla in man (Fig. 1.38).

The upper part of the face is completed by fusion of the frontonasal and maxillary processes in the above manner, but at first the face is only a mask, for behind it the nasal septum and palate have yet to be completed. The developing tongue lies against the floor of the cranium. A midline flange (the nasal septum) grows down from the base of the forebrain capsule (which is the mesenchymal precursor of the skull). From each maxillary process a flange known as the **palatal process** grows medially across the dorsum of the tongue. The two palatal processes and the nasal septum meet and unite from before backwards, thus separating the nasal cavities from each other and from the mouth. So is formed the **nasal capsule**, in mesoderm. Chondrification of the nasal capsule occurs, and by the sixth week the nasal walls and hard palate are outlined by a thin layer of hyaline cartilage. Ossification of the cartilaginous nasal capsule begins almost at once, spreading from several centres. In the upper part of the wall of the nose the hyaline cartilage is itself replaced by bone, but in the lower part of the septum and in the hard palate there is a deposition of membrane bone on each surface of the hyaline cartilage. The cartilage, thus sandwiched between two layers of membrane bone, is not absorbed until some time after birth.

The nerve supply of all these structures, *inside and outside*, is derived from the fifth cranial (trigeminal) nerve. The frontonasal process and its derivatives are supplied by the ophthalmic division, the maxillary process and its derivatives by the maxillary division and the lower jaw by the mandibular division.

Defects of development

The commonest abnormalities are harelip and cleft palate (1 in 1000 and 1 in 2500 births respectively) which may or may not coexist. **Harelip** is almost always lateral; the cleft runs down from the nostril. The median part of the lip is derived in these cases from the opposite

maxillary process or, perhaps, from the frontonasal process which latter normally does not produce any part of the upper lip. Harelip may be bilateral, in which case the central part of the lip, between the two clefts, is obviously derived, abnormally, from the frontonasal process.

Cleft palate may be partial or complete. The two palatal processes unite with each other (and with the nasal septum) from before backwards. Arrest of union thus results in a posterior defect that varies from the mildest form of bifid uvula to a complete cleft from uvula to gum margin. In the latter case the cleft almost always runs between premaxilla and maxilla and involves the jaw between the lateral incisor and canine teeth. Irregular formations of incisor and canine teeth, however, often accompany these defects of palatal development. Very rarely a midline cleft may separate the two halves of the premaxilla.

A less common defect arises from the failure of fusion of the lateral nasal process with the maxillary process, producing a groove (*facial cleft*) on the face along the line of the nasolacrimal duct. Reduplication of various forms produces monsters, completely two-headed or less grotesque, while fusion results in such conditions as cyclopia.

DEVELOPMENT OF THE CLOACA

At the caudal end of the embryo, the hindgut and the allantois (a diverticulum from the endoderm of the yolk sac) meet in a common cavity, the **cloaca**, bounded distally by the **cloacal membrane** (Fig. 1.39A). From the dorsal wall of the allantois, the **urorectal septum** grows downwards to meet the cloacal membrane, so dividing the cloaca and membrane into two (Fig. 1.39B): at the front, the urogenital sinus and urogenital membrane, and at the back the anorectal canal and the anal membrane, which lies in a small ectodermal depression, the **proctodeum**. This dorsal part of the sinus becomes the rectum and anal canal (p. 380).

The **urogenital sinus** (endoderm) has three unequal-sized parts. The uppermost and largest is the **vesical (vesicourethral) part**, which forms most of the bladder epithelium (with surrounding mesoderm forming the muscle and connective tissue) and the female urethra (Fig. 1.39D); in the male the lower part becomes the proximal prostatic urethra as far as the openings of the ejaculatory ducts and prostatic utricle. The lower end of the mesonephric duct (p. 370) opens into this part of the sinus, and the ureter forms as a bud from the duct. The duct and ureter grow apart and open separately into the sinus, with the ureter opening at a higher level than the duct. The lower ends of the

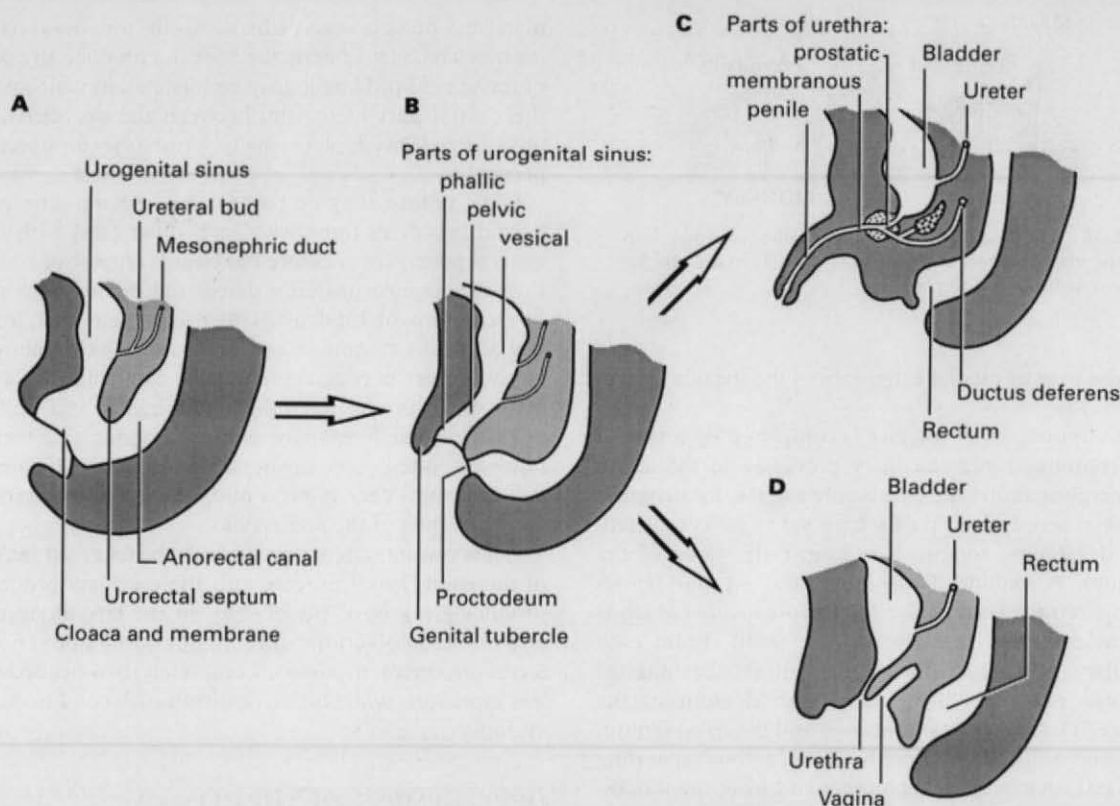


Fig. 1.39 Development of the cloaca. **A** The urorectal septum grows down to divide the cloaca into the urogenital sinus and the anorectal canal. **B** The uppermost (vesicourethral) part of the sinus becomes the bladder and the proximal part of the prostatic urethra, with the pelvic and phallic parts distally. **C** In the male the pelvic part becomes the prostatic urethra distal to the opening of the ejaculatory ducts, and the phallic part becomes the dorsal part of the penile urethra. **D** In the female the bladder and urethra are from the vesicourethral part of the sinus.

duct and ureter become incorporated into the developing bladder, so forming the *trigone*, with the lowest part of the duct becoming the ejaculatory duct opening into the prostatic urethra (Fig. 1.39C).

The middle or *pelvic part* of the sinus forms the rest of the prostatic urethra, the membranous urethra and the prostate (with surrounding mesoderm forming the fibromuscular stroma). In the female it contributes epithelium to the vagina (derived principally from the paramesonephric ducts, p. 309).

The lowest or *phallic part* of the sinus becomes the dorsal part of the penis and penile urethra or the vestibule of the vagina. At the front of the urogenital membrane (which breaks down) is a midline mesodermal swelling, the *genital tubercle* (Fig. 1.39B), which becomes the clitoris or the glans penis. Leading back from the tubercle on either side are the *urogenital folds*, which in the female remain separate as the labia minora. In the male they unite at the back to form the midline raphe of the scrotum, the rest of the scrotum

coming from the pair of *genital (labioscrotal) swellings* which develop lateral to the urogenital folds and which in the female become the labia majora. The front parts of the urogenital folds unite from the scrotum forwards as the ventral part of the penis and penile urethra.

CARDIAC AND VENOUS DEVELOPMENT

The origin of the pulmonary trunk and of the aorta and its main branches to the head and neck have been covered with the branchial arches (above). For the rest of the vascular system, some introductory remarks must be made on early heart development and the origins of the major veins.

Early development of the heart

Primitive blood vessels are laid down by angioblasts on the wall of the yolk sac. Two such vessels fuse together to make a single **heart tube** which develops muscle

fibres in its wall and becomes pulsatile. It differentiates into four parts or cavities which in a cephalocaudal direction are the **bulb**, **ventricle**, **atrium** and **sinus venosus**. The tube grows at a greater rate than the cavity (the primitive pericardium) in which it is suspended; it therefore has to bend, and it does so in such a way that the bulb and the ventricle come to lie in front of the atrium and sinus venosus. There is also a slight twisting of the bulb to the right and the ventricle to the left, hence the normal left-sided bulging of the definitive heart.

The upper part of the bulb is the *truncus arteriosus*, which divides to become the aorta and pulmonary trunk. The lower part of the bulb becomes most of the right ventricle, with the original ventricle forming most of the left ventricle. The atrium becomes divided into two, with the sinus venosus becoming mostly absorbed into the right atrium. These later changes are described on page 275.

Development of veins

From a network of primitive veins, certain longitudinal channels develop to return blood to the **sinus venosus**. It receives blood from three sources: from the *placenta* by *umbilical veins*, from the *yolk sac* (which becomes the alimentary canal) by *vitelline veins*, and from the *general tissues* of the embryo by *cardinal veins*. In each group there are right and left veins, with anastomosing cross-channels between each pair, and the whole or part of one longitudinal vein of each pair disappears — right umbilical, left vitelline and left cardinal.

The *left umbilical vein* joins the left branch of the portal vein, but its blood short-circuits the liver by passing along a venous shunt, the *ductus venosus*, which joins the end of the right vitelline vein on the cranial side of the liver. After birth the left umbilical vein and its continuation the ductus venosus become reduced to fibrous cords, the *ligamentum teres* and *ligamentum venosum*.

The fate of the *vitelline veins*, which with their cross-channels contribute to the formation of the portal vein and the upper end of the inferior vena cava, is considered with the portal vein (p. 351).

On each side, a vein from the head and neck (internal jugular) and from the upper limb (subclavian) unite to form the *anterior cardinal vein*. Similarly, from the lower limb and pelvis, external and internal iliac veins form the *posterior cardinal vein*, into which drain segmental veins (intercostal and lumbar). The two cardinals unite to form the *common cardinal vein* (the duct of Cuvier of comparative anatomy). The essential features of subsequent changes are the obliteration of the left anterior

and posterior cardinals, with the persistence of a cross-channel at each end of the body — the left brachiocephalic vein and the left common iliac vein.

In the *thorax* the right anterior cardinal vein forms the right brachiocephalic and the superior vena cava as far as the entry of the azygos vein (derived from the right posterior cardinal). On the left a hemiazygos system develops to replace the vanished left posterior cardinal vein.

In the *abdomen* the fate of the posterior cardinal veins is more complicated, since other longitudinal channels appear both medial (subcardinal) and dorsal (supracardinal) to the original posterior cardinal. The end result is the formation of the inferior vena cava and its tributaries from different parts of these vessels and their intercommunications. Details can be found in embryological texts, but for most students they are an unnecessary burden, although they do of course provide explanations for the asymmetry of the vena caval tributaries and venous anomalies. Suffice it to say here that in the lower abdomen the common *iliac veins* are *behind* the corresponding arteries, but higher up the *renal veins* are *in front of* the renal arteries, due to the venous development from dorsal or ventral channels — iliacs from dorsal, renals from ventral. It should also be noted that the so-called *left-sided inferior vena cava* is only left-sided in its *lower* part; its upper end is still to the right of the aorta but the lower part joins the left renal vein which may cross either in front of or behind the aorta.

PART 4 ANATOMY OF THE CHILD

The proportions of the newborn child differ markedly from the form of the adult. Some of its organs and structures are well developed and even of full adult size (e.g. the internal ear) while others have yet to develop (e.g. corticospinal tracts to become myelinated, teeth to erupt, secondary sex characters to appear).

It is proposed to consider several features of a general nature, followed by accounts of certain special parts of the body, but before doing so it seems convenient to discuss first the circulatory changes which take place in the neonatus at the time of birth.

FETAL CIRCULATION

The fetal blood is oxygenated in the placenta, not in the lungs. The economy of the fetal circulation is improved by three short-circuiting arrangements, all of which

cease to function at the time of birth: the ductus venosus, the foramen ovale and the ductus arteriosus.

Ductus venosus

Oxygenated blood returns from the placenta by the (left) umbilical vein, which joins the left branch of the portal vein in the porta hepatis. This oxygenated blood short-circuits the sinusoids of the liver; it is conveyed directly to the inferior vena cava by the *ductus venosus*. This channel lies along the inferior surface of the liver, between the attached layers of the lesser omentum. After birth, when blood no longer flows along the thrombosed umbilical vein, the blood in the ductus venosus clots and the ductus venosus becomes converted into a fibrous cord, the *ligamentum venosum*, lying deep in the cleft bounding the caudate lobe of the liver. The intra-abdominal part of the umbilical vein persists as a fibrous cord, the *ligamentum teres*. The two are continuous.

Foramen ovale

The interatrial septum of the fetal heart is patent, being perforated by the *foramen ovale*. Blood brought to the right atrium by the inferior vena cava is directed by its 'valve' through the foramen and so enters the left atrium. The oxygenated placental blood is thus made to bypass the right ventricle and the airless lungs, and is directed into the left ventricle and aorta and so to the carotid arteries.

After birth the foramen ovale is closed by fusion of the primary and secondary septa (p. 275). After closure all the blood in the right atrium perforce passes into the right ventricle and so to the lungs.

The continuing patency of the interatrial septum until birth and its prompt closure after the first breath enters the lungs provide an admirable example of correlation between form and function.

Ductus arteriosus

It has already been noted that oxygenated blood in the umbilical vein passes via the ductus venosus, inferior vena cava and right atrium through the foramen ovale to the left side of the heart and so to the head. Venous blood from the head is returned by way of the brachiocephalic veins to the superior vena cava. In the right atrium this venous blood stream crosses the stream of oxygenated blood brought there via the inferior vena cava. The two streams of blood scarcely mix with each other. The deoxygenated blood from the superior vena cava passes through the right atrium into the right

ventricle and so into the pulmonary trunk. It now short-circuits the airless lungs by the *ductus arteriosus*. This is a thick artery joining the left branch of the pulmonary trunk to the aorta, distal to the origin of the three branches of the aortic arch. The deoxygenated blood thus passes distally along the aorta and via the umbilical arteries to the placenta to be reoxygenated.

After birth the ductus arteriosus is occluded by contraction of its muscular walls. It persists as a fibrous band, the *ligamentum arteriosum*, which connects the commencement of the left pulmonary artery to the concavity of the arch of the aorta. After the closure of the ductus blood from the right ventricle perforce circulates through the lungs.

GENERAL FEATURES OF THE NEWBORN

Of all the mammalian newborn the human is perhaps the least graceful. Kittens and puppies, lambs and foals, and most other newborn mammals possess a beauty and grace in their playful movements that are lacking in the human young. Man is born in a more immature form and requires some months to reach the kitten or puppy stage.

In comparison with the adult the neonatus is much more fully developed at its head end than at its tail end. The large head and massive shoulders stand out in marked contrast to the smallish abdomen and poorly developed buttocks and lower limbs. The edentulous jaws and shallow maxillae combine to produce a face short in its vertical extent, with the cheeks bulging forwards to accommodate their tissues. The bulging cheeks of the baby face are not entirely lost until eruption of the permanent teeth and the rapid increase in size of the maxillary sinuses between the ages of 6 and 7 years.

The newborn baby has no visible neck; its lower jaw and chin touch its shoulders and thorax. Gradually the neck elongates and the chin loses contact with the chest. The head thus becomes more mobile, both in flexion-extension and in rotation.

The abdomen is not prominent at birth but becomes gradually more and more so. The 'pot-belly' of the young child is due mainly to the large liver and the small pelvis; the pelvic organs lie in the abdominal cavity. In later childhood the pelvic organs and much of the intestinal tract sink into the developing pelvic cavity and the rate of growth of the abdominal walls outpaces that of the liver. In this way the disposition of the viscera and the contour of the abdominal wall reach the adult proportions, and the bulging belly flattens.

The limbs are disproportionately developed. The upper limb is well developed at birth, but its

movements are ill-controlled and ataxic. Fingers can be flexed and hyperextended and there is a very powerful grasping reflex, so that the neonatus can hold itself suspended by the grip of its hand. The hand takes many months to become the chief tactile organ — until this time the lips are used for feeling, the hand functioning merely as the prehensile organ to convey objects to the mouth for examination. The small buttocks and short legs give little indication of the form and function they will later attain.

SOME SPECIAL FEATURES OF THE NEWBORN

The skull

The most striking feature of the neonatal skull is the disproportion between the cranial vault and facial skeleton; the vault is very large in proportion to the face.

In Figure 1.40 the photograph of a full-term fetal skull has been enlarged to the same vertical projection as a normal adult skull and this procedure shows in striking manner the disproportion between the two.

The rotundity of the fetal skull in comparison with the adult is mainly the result of underdevelopment of the face. The cranial vaults in this frontal view are of much the same proportions. There is a very great difference in the facial skeletons. In the fetal skull the vertical diameter of the orbit equals the vertical height of maxilla and mandible combined. In the adult skull the growth of the maxillary sinuses and the growth of alveolar bone around the permanent teeth has so elongated the face that the vertical diameter of the orbit is only one-third of the vertical height of maxilla and mandible combined.

The bones of the vault of the skull and face are developed by ossification in membrane, the base of the skull by ossification in cartilage. Most of the separate skull and face bones are ossified by the time of birth but they are mobile on each other and are fairly readily disarticulated in the macerated skull. Their mobility on each other is most marked in the vault and the ability to overlap provides that moulding of the cranium which so generally occurs during parturition.

The bones of the vault (frontal, parietal, occipital, squamous, etc.) do not interdigitate in sutures, as in the

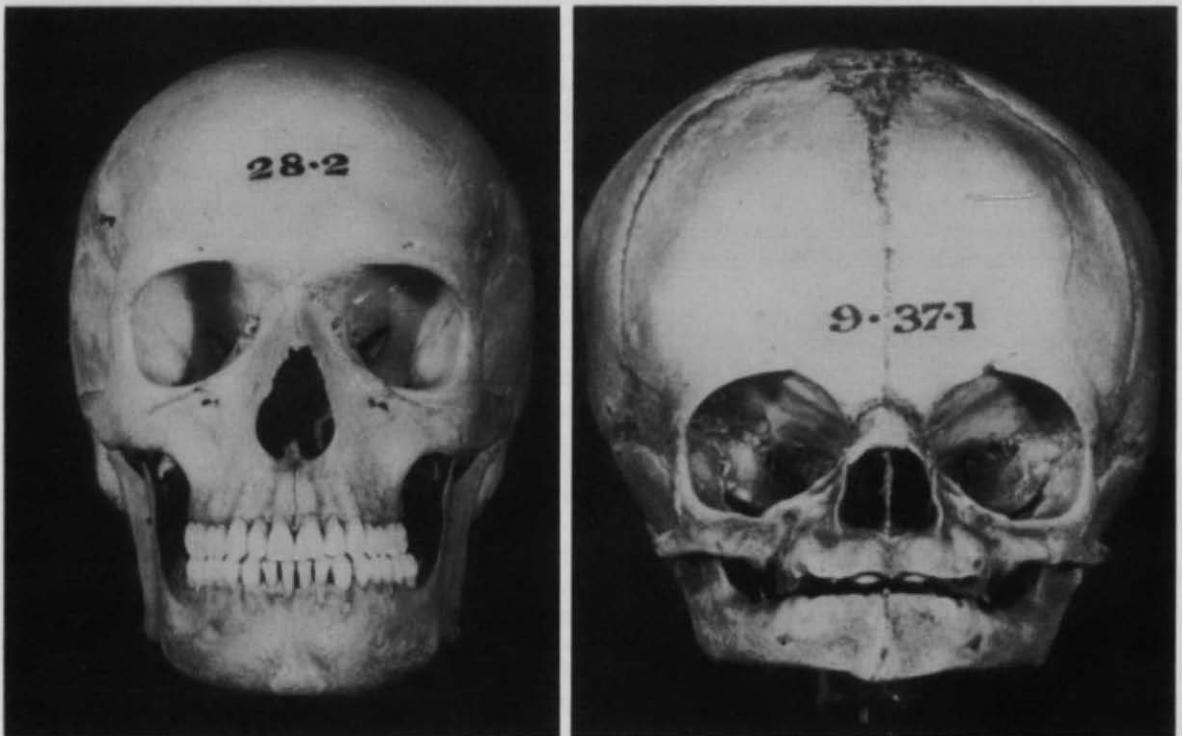


Fig. 1.40 Normal adult and fetal skulls. The fetal skull on the right is projected to the same vertical height as that of the adult. Note the disproportion of the vertical extent of the face. The distance from the lower margin of the orbit to the lower border of the mandible in the adult is three times the diameter of the orbit; in the fetal skull it is equal to the diameter of the orbit.

adult, but are separated by linear attachments of fibrous tissue and, at their corners, by larger areas, the fontanelles. The anterior and posterior fontanelles are the most readily examined, for they lie in the midline of the vault.

The **anterior fontanelle** lies between four bones. The two parietal bones bound it behind, the two halves of the frontal bone lie in front. The two halves of the frontal bone unite by the second year; the anterior fontanelle is closed by this time — clinically it is usually not palpable after the age of 18 months. The extent of the anterior fontanelle is indicated in the adult skull by relatively straight parts of the coronal and sagittal sutures (p. 644).

The **posterior fontanelle** lies between the apex of the squamous part of the occipital bone and the posterior edges of the two parietal bones. It is closed at the end of the first year.

Growth of the vault of the skull takes place by deposition of bone around the edges of the separate bones, which come to interdigitate with each other along the various sutures. But in addition to this appositional growth there is interstitial growth in thickness, *accompanied regularly throughout by a moulding of each bone*, i.e. absorption of inner surfaces of bone by osteoclasts accompanies the laying down of new external surfaces of bone by osteoblasts. An adult parietal bone, for example, is the surface of a larger sphere than that of the neonatal parietal bone, though some slight persistence of the infantile curvature is indicated at the parietal eminence. In the vault only compact bone is present at birth; with subsequent growth the interior of the bones becomes excavated into cancellous bone (the *diploë*), and red bone marrow fills the interstices.

Temporal bone and ear

The temporal bone develops in four separate pieces, two in membrane and two in cartilage. The squamous and tympanic bones develop in membrane, the petromastoid and styloid process in cartilage.

The **squamous part** resembles the adult and increases in size by appositional growth combined with a continuous process of moulding.

The **tympanic part** is present at birth as the C-shaped *tympanic ring*, applied to the under surface of the petrous and squamous parts and enclosing the tympanic membrane, which is slotted into it. The external acoustic meatus of the newborn is wholly cartilaginous. The tympanic membrane is almost as big as in the adult, but faces more downwards and less outwards than the adult ear drum; it therefore seems somewhat

smaller and lies more obliquely when viewed through the otoscope. The tympanic ring elongates by growth from the lateral rim of its whole circumference, the tympanic plate so produced forming the bony part of the external acoustic meatus and pushing the cartilaginous part of the meatus laterally, further from the ear drum. The adult bony meatus is thus twice as long as the cartilaginous part.

As the tympanic plate grows laterally from the tympanic ring the tympanic membrane tilts and comes to face rather more laterally and less downwards than in the neonate. Growth of bone from the C-shaped tympanic ring is at first more rapid anteriorly and posteriorly, and less rapid inferiorly. The growing anterior and posterior bony flanges usually join and enclose an irregular foramen (of Huschke) between them, but subsequent growth of bone obliterates this gap.

The **petromastoid or petrous part** encloses the internal ear and tympanic antrum, all parts of which are *full adult size at birth*. The mastoid process is not developed and the stylomastoid foramen is near the lateral surface of the skull, covered by the thin fibres of sternocleidomastoid — the issuing facial nerve is thus unprotected and vulnerable at birth. The mastoid process develops with growth of the sternocleidomastoid muscle as the child commences to move its head, and air cells grow into it from the mastoid (tympanic) antrum. The mastoid process is aerated in this way at the beginning of the second year (the same time as the frontal sinus appears).

As already stated the cochlea, vestibule and semi-circular canals are full adult size at birth. The middle ear is roofed in by a plate of bone, the tegmen tympani, which projects laterally from the petrous bone. At birth the tegmen tympani is not fully grown and it does not cover the geniculate ganglion of the facial nerve; the ganglion is in contact with the dura mater of the middle cranial fossa. The chorda tympani leaves the middle ear and emerges from the base of the skull between the tympanic ring and the under surface of the squamous bone. As the tympanic ring grows laterally and becomes the scroll-shaped tympanic plate the chorda tympani comes to emerge between it and the squamous part of the temporal bone, i.e. through the squamotympanic fissure. By this time the tegmen tympani of the petrous part of the temporal bone has grown across the geniculate ganglion and curved downwards to form the lateral wall of the canal for the tensor tympani muscle. Its growing edge peeps out from the medial part of the squamotympanic fissure, dividing that fissure into petrosquamous in front and petrotympanic behind (Fig. 8.4, p. 646). The chorda tympani is caught behind the down-growing tegmen tympani and thus emerges

from the base of the skull through the petrotympanic fissure.

The mastoid antrum is full adult size at birth and is generally covered by some 3 mm of petrous bone deep to the floor of the suprameatal triangle. After ossification of the petrosquamous suture new bone from the squamous 'flows down' over the developing mastoid process, and at the rate of 1 mm a year buries the mastoid antrum more deeply. This growth stops at 12 years; thereafter the antrum lies 15 mm from the surface. The squamomastoid 'suture' becomes an irregular line above the margins of the mastoid process (Fig. 6.58, p. 524)

Face

The **maxilla**, between the floor of the orbit and the gum margin, is very shallow at birth and is full of developing teeth. The maxillary sinus is a narrow slit excavated into its medial wall. Eruption of the deciduous teeth allows room for excavation of the sinus beneath the orbital surface but the maxilla grows slowly until the permanent teeth begin to erupt at 6 years. At this time it 'puts on a spurt' of growth. The rapid increase in size of the sinus and the growth of the alveolar bone occur simultaneously with increased depth of the mandible. These factors combine to produce a rapid elongation of the face.

The hard palate grows backwards to accommodate the extra teeth, but the forward growth of the base of the skull at the occipital sutures outstrips it and prevents the hard palate from approaching the cervical vertebrae. So the nasopharyngeal isthmus is kept open,

and in fact increases in size. After eruption of the first permanent molar (6 years) the suture between basi-occiput and the jugular part closes but forward growth of the base of the skull continues at the spheno-occipital synchondrosis and this latter does not ossify until well after the third molar is either erupted or fully formed (25 years of age).

The paranasal sinuses are rudimentary at birth. Their development and growth are considered on page 476). Growth of the face occurs by overall increase in size of all the face bones; most of the sutures slope downwards and backwards, so that growth at the sutures forces the face downwards and forwards away from the base of the skull.

The **mandible** is in two halves at birth; the fibrous joint (called symphysis menti, although it is not a true symphysis, being only fibrous tissue without any cartilage) between them ossifies at the end of the first year. The body of the mandible is practically 'full of teeth', so the mental foramen lies near its lower border. After eruption of the permanent teeth the foramen lies halfway between the upper and lower borders of the bone. In the edentulous jaw absorption of the alveolar margin leaves the mental foramen nearer the upper border of the mandible, so exposing the mental nerve to the pressure of an artificial denture (Fig. 1.41). Elongation of the body of the mandible is required to accommodate the erupting teeth and keep them in occlusion with the increasing number of maxillary teeth. Elongation of the ramus of the mandible is also required, for the jaws must separate to allow room for the eruption of the teeth. With growth in width of the face the mandible widens correspondingly. This overall

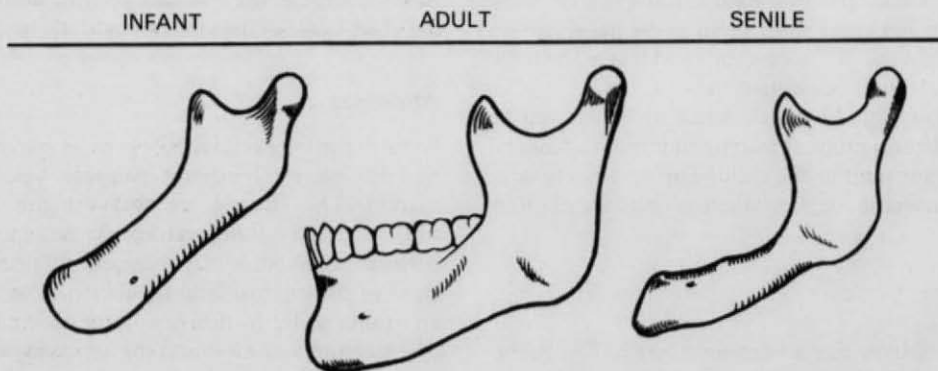


Fig. 1.41 Age changes in the mandible. Lateral outlines of the infant, adult and senile mandibles are seen, not as dried bones resting on the table but as in the resting position in the living head (with the infant outline enlarged to adult proportions). The position of the temporomandibular joint does not change; in the senile mandible the alveolar process becomes resorbed, leaving the (unlabelled) mental foramen very near the upper margin.

growth of the mandible takes place, as in all bones of the body, by a process of moulding which results from the harmonious deposition of new bone and resorption of old bone where required. An 'epiphysis' at the neck of the mandible (composed of secondary cartilage) allows ready moulding of the condyle of the bone for accommodation with the changing size and direction of the articular cartilage and temporal bone.

These growth changes produce alterations in the contour of the mandible that are very characteristic (Fig. 1.41). At birth the angle is obtuse and the coronoid process lies at a higher level than the condyle; the latter lies in line with the upper border of the body. The resting mandible is depressed and the tongue lies between the edentulous gums, and the adult rest position of the mandible is not reached until the age of about 2 years. After eruption of the permanent teeth the angle is more nearly a right angle, and the well-developed condyle lies higher than the coronoid process. In the edentulous mouth the angle of the mandible does not alter very significantly, but gradual moulding of the neck ultimately depresses the condyle to a lower level than the coronoid process.

These age variations in the relative upward protrusion of coronoid process and condyle are much more apparent than real, for they are measured in relation to the working position of the mandible, with the occlusal surface horizontal. In the resting position, however, the infantile and edentulous senile mandible are in each case more open than in the normal adult (Fig. 1.41), and this accounts for the apparent disproportion of the two bony processes.

The tongue is relatively large at birth and has a blunt tip that cannot be extruded. The newborn is 'tongue-tied' and only slowly does the tip of the tongue elongate. The hard palate is high and the orifice of the auditory tube lies at the same level; as the nasal septum grows in height the palate descends and leaves the tubal orifice above it in the nasopharynx.

In common with lymphatic tissue elsewhere in the body the palatine and nasopharyngeal tonsils (adenoids) tend to be exuberant in the child. Their relatively large size should never in itself be taken as evidence of infection.

Neck

The newborn baby has a very short neck. The subsequent elongation of the neck is accompanied by growth changes in the covering skin; an incision over the lower neck in an infant usually results in the scar lying over the upper sternum by later childhood.

The left brachiocephalic vein crosses the trachea so

high in the superior mediastinum that it lies above the jugular notch into the neck, especially if it is engorged and the head extended; this should be remembered by the surgeon performing tracheotomy upon the young child.

The shortness of the neck of the newborn involves a higher position of its viscera. The epiglottis and larynx lie relatively nearer the base of the tongue and their descent is slow; they reach their adult levels only after the seventh year. The larynx and trachea are of small bore at birth. The vocal cords are about 5 mm long by the end of the first year. Laryngitis and tracheitis in infancy thus carry far more risk of respiratory obstruction than they do in later years. Up to the age of puberty there is no difference between the male and female larynx. At puberty the male larynx increases rapidly in size and the vocal cords elongate from 8 to 16 mm within the year, resulting in the characteristic 'breaking' of the voice. Castration or failure of testicular hormone prevents this change taking place.

Thorax

The thoracic cage of the child differs from that of the adult in being more barrel-shaped. A cross-section of the infant thorax is nearly circular; that of the adult is oval, the transverse being thrice the length of the antero-posterior diameter. The large thymus extends from the lower part of the neck through the superior into the anterior mediastinum; it regresses at puberty. The ribs lie more nearly horizontal, so the cage is set at a higher level than in the adult. This results in the shortness of the neck already noted. The high thorax involves a higher level of the diaphragm, with consequent increase of abdominal volume. Descent of the thoracic cage as the ribs take up their adult obliquity is the chief cause of the elongation of the neck.

Abdomen

At birth the liver is relatively twice as big as in the adult and its inferior border is palpable below the costal margin. The kidneys are always highly lobulated at birth with very little perinephric fat; grooves on the surface of the adult organ frequently persist as visible signs of the original fetal lobulation. The suprarenal is enormous at birth, nearly as large as the kidney itself. The caecum is conical and the appendix arises from its apex in the fetus, and this arrangement is usually still present at birth. During infancy and early childhood the lateral wall of the caecum balloons out and the base of the appendix comes to lie posteriorly on the medial wall. The appendiceal mucous membrane is packed

with massed lymphoid follicles in the child. These become much more sparse in later life. The pelvic cavity is very small at birth and the fundus of the bladder lies above the pubic symphysis even when empty.

Upper limb

The upper limb is more fully developed than the lower limb at birth. The grasping reflex of the hand is very pronounced. Growth in length occurs more at the shoulder and wrist than at the elbow. Amputation through the humerus in a young child requires a very generous flap of soft tissue lest the growing bone should later protrude through the stump.

Lower limb

At birth the lower limb is not only poorly developed, but occupies the fetal position of flexion, a position which is maintained for 6 months or more. In preparation for standing and walking the limb not only becomes more robust, but undergoes an extension and medial rotation that carry the flexor compartment around to the posterior aspect of the limb. The inverted

foot of the newborn gradually becomes everted harmoniously with these changes in position of the knee and hip joints. Growth of the limb proceeds more rapidly at the knee than at the hip or ankle. It is not symmetrical across the lower epiphysis of the femur, and 'knock-knee' (genu valgum) is normal in the child.

Vertebral column

Until birth the column is C-shaped. This is imposed by constriction in utero. After birth the column is so flexible that it readily takes on any curvature imposed by gravity. The cervical curve opens up into a ventral convexity when the infant holds up its head and the lumbar curve opens up into a ventral convexity when the infant walks. The extension of the hip that accompanies walking tilts the pelvis forwards, so that the axis of the pelvic cavity is no longer in line with that of the abdominal cavity. This forward tilt of the pelvis necessitates a high degree of forward curvature (lordosis) of the lumbar spine in order to keep the body vertical in the standing position.

The spinal cord extends to L3 vertebra at birth and does not 'rise' to L2 until adult years.

2. Upper limb

GENERAL PLAN

The upper limb of man is built for prehension. The hand is a grasping mechanism, with four fingers flexing against an opposed thumb. The hand is furthermore the main tactile organ, with a rich nerve supply, particularly of the flexor compartment (p. 22).

In grasping, the thumb is equal in functional value to the other four fingers; loss of the thumb is as disabling as loss of all four fingers. In order to be able to grasp in any position the forearm is provided with a range of 180° of pronation and supination, and at the elbow has a range of flexion and extension of like amount. In addition, very free mobility is provided at the shoulder joint, and this mobility is further increased by the mobility of the pectoral girdle through which the upper limb articulates with the axial skeleton.

Although the upper limb is commonly called the arm, this term strictly refers to the upper part of the limb between the shoulder and elbow. Both the arm and the forearm (below the elbow) have anterior or flexor and posterior or extensor compartments.

There are many similarities between the upper and lower limbs, but obviously it is difficult to compare the two until the anatomy of both is understood. For this reason, discussion of this topic is deferred until page 235 after both limbs have been described.

PART 1

PECTORAL GIRDLE

Limb girdles are defined as the bones that connect the limbs to the axial skeleton. The bones of the pectoral or shoulder girdle are the clavicle and scapula. Only one small joint connects the girdle to the rest of the skeleton — the sternoclavicular joint — and the two bones are joined to one another by an even smaller joint, the acromioclavicular. The remaining attachment to the

axial skeleton is purely muscular, and this helps to account for the greater mobility of the shoulder girdle compared with its lower limb counterpart (p. 144), where three bones (ilium, ischium and pubis) fuse to form the solid hip bone or pelvic girdle.

In terms of comparative anatomy, the human scapula represents two bones that have become fused together; the (dorsal) scapula proper and the (ventral) coracoid. The epiphyseal line across the glenoid cavity is the line of fusion (Fig. 2.9). They are the counterparts of the ilium and ischium of the pelvic girdle. The counterpart of the pubis is a tiny piece of bone (precoracoid) that ossifies separately at the tip of the coracoid process; it takes no part in the formation of the shoulder joint. The clavicle, ossifying in membrane, is an added bone (it has no counterpart in the pelvic girdle) whose purpose is to act as a strut preventing medial movement of the scapula. The strong coracoclavicular ligament attaches the clavicle and scapula to each other, and the clavicle is anchored to the first costal cartilage by the costoclavicular ligament. Forces from the upper limb are transmitted by the clavicle to the axial skeleton through these ligaments, and neither end of the clavicle normally transmits much force.

Embryology

Muscles developed in the upper limb are supplied by branches from the brachial plexus. During their development some of these muscles migrate for considerable distances to gain attachment to the trunk; but they continue to be innervated from the brachial plexus. Motor supply, once established in the embryo, never changes thereafter. An example is latissimus dorsi which, notwithstanding its very wide attachment to the trunk, still retains its supply from the posterior cord of the brachial plexus. Other muscles, not developed in the limb, migrate from the trunk and gain attachment to the girdle; e.g. sternocleidomastoid and trapezius, supplied by the accessory nerve, attach themselves to

clavicle and scapula. The nerve supply tells the story of the development of any muscle.

Movements

The essential functional requirement of the pectoral girdle is mobility on the thorax to enhance the mobility of the shoulder joint. And it is a fact that all movement between humerus and glenoid cavity, except very slight movement, is accompanied by an appropriate movement of the scapula itself. Nor can the scapula move without making its supporting strut, the clavicle, move also. Generally speaking the shoulder joint, the acromioclavicular and sternoclavicular joints all move together in harmony, providing a kind of 'thoraco-humeral articulation'. It is important to appreciate this, for functional defects in any part of the 'thoraco-humeral articulation' must impair the whole. But to understand the mechanisms involved, it is essential to analyse the composite movement into its constituent parts, and this is done with the glenohumeral joint on page 76 and with the clavicular joints on pages 61 and 62.

The bones of the pectoral girdle are described on page 127.

MUSCLES OF THE PECTORAL GIRDLE

The muscular attachments between pectoral girdle and trunk are direct and indirect.

Direct attachment of the pectoral girdle to the trunk is provided by muscles that are inserted into the clavicle or scapula from the axial skeleton. These muscles are pectoralis minor, subclavius, trapezius, the rhomboids, levator scapulae and serratus anterior. Indirect attachment to the axial skeleton is secured by the great muscles of the axillary folds (pectoralis major and latissimus dorsi); these muscles, by way of the upper end of the humerus, move the pectoral girdle on the trunk. Their descriptions are included here.

The muscular attachments between upper limb and pectoral girdle include the deltoid and short scapular muscles, which are inserted about the upper end of the humerus, and the biceps and long head of triceps which, running over the humerus, are inserted beyond the elbow joint into the bones of the forearm. All these muscles are important factors in giving stability to the very mobile shoulder joint across which they lie, and are described with the shoulder region (p. 72).

Pectoralis major

From clavicular and sternocostal heads this large triangular muscle converges on the upper humerus, folding

on itself where it forms the anterior axillary wall to become attached to the humerus by means of a trilaminar tendon.

The *clavicular head* arises from the medial half of the anterior surface of the clavicle over a smooth flattened area which is easily seen on most clavicles. Running almost horizontally laterally the fibres of this head lie in a groove on the manubrial part of the muscle, from which they are quite separate. They are inserted by the anterior lamina of the tendon into the lateral lip of the intertubercular (bicipital) groove of the humerus, into the anterior lip of the deltoid tuberosity and, below that, into the deep fascia of the arm.

The *sternocostal head* arises from the lateral part of the anterior surface of the manubrium and body of sternum, and from the aponeurosis of the external oblique muscle over the upper attachment of rectus abdominis. On the deep surface of this sheet of muscle, and in continuity with it, fibres arise by a series of slips from the upper six costal cartilages. The manubrial fibres are inserted by tendon into the lateral lip of the intertubercular groove behind (deep to) the clavicular fibres as far down as the upper part of the deltoid tuberosity. They form the intermediate lamina of the insertion. The sternocostal fibres, arising from below the sternal angle, course upwards and laterally to be inserted progressively higher into the posterior lamina of the tendon, producing the rounded appearance of the anterior axillary fold. The fibres which arise lowest of all are thus inserted highest of all in the posterior leaf of the tendon. The uppermost limit of the insertion of the posterior leaf is, by a crescentic fold, into the capsule of the shoulder joint (Fig. 2.1). The anterior leaf is not inserted as high as this, its uppermost limit being on a level with the surgical neck of the humerus.

Like most limb girdle muscles, there is some doubt about how much of pectoralis major is developed from the limb bud and how much from myotomes of the trunk, with migration in either direction. On dissection 1 body in 20 shows the presence of vertical musculo-aponeurotic fibres on the surface of the pectoralis major alongside the sternum (Fig. 2.2). This is the **rectus sternalis muscle**, a derivative of the superficial layer of the rectus abdominis (p. 298); it is supplied segmentally by intercostal nerves. Its upper fibres usually fuse with the sternal tendon of sternocleidomastoid.

Nerve supply. From the brachial plexus via the medial and lateral pectoral nerves, so named because of their origins from the medial and lateral cords of the plexus. The medial pectoral pierces pectoralis minor (and therefore supplies it) and the lateral pectoral pierces the clavipectoral fascia medial to the pectoralis minor. Both nerves enter the deep surface of pectoralis

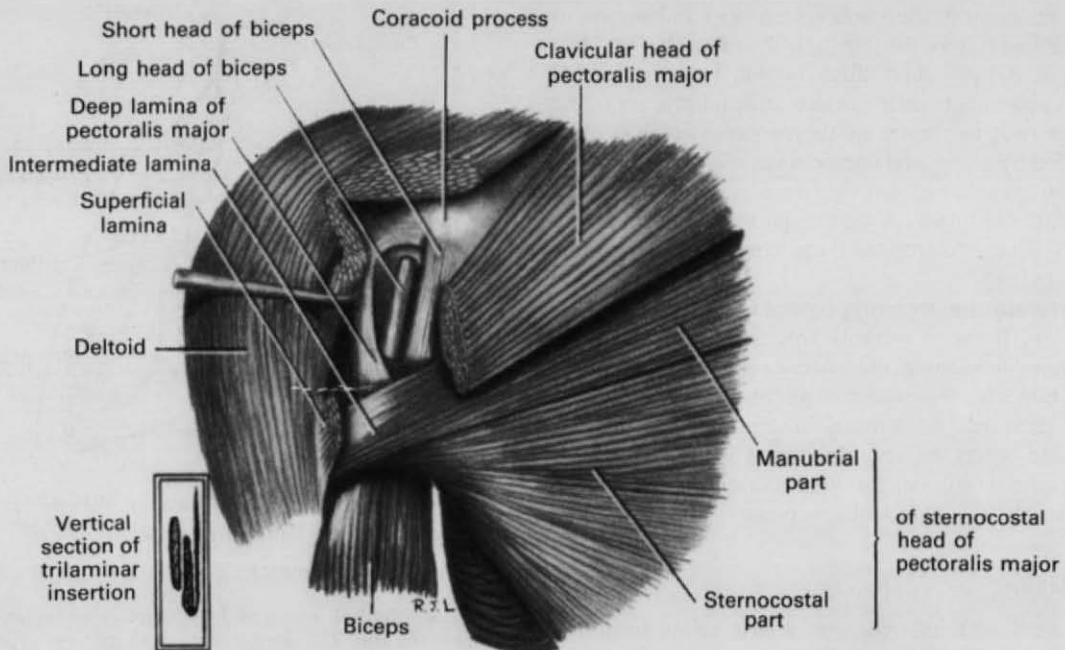


Fig. 2.1 Insertion of the right pectoralis major. Part of the clavicular head has been removed and deltoid incised and retracted to show how the lowest fibres of the sternocostal origin twist upwards deep to the manubrial fibres.

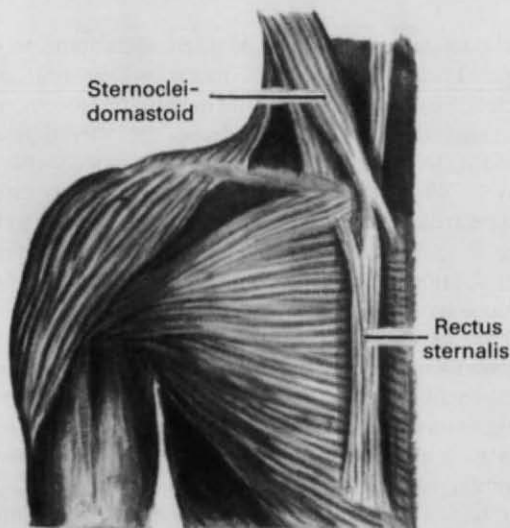


Fig. 2.2 Right rectus sternalis, an occasional derivative of rectus abdominis.

major. The muscle is the *only one* in the upper limb to be supplied by *all five segments* of the brachial plexus; C5, 6 supply the clavicular head and C7, 8, T1 the sternocostal part, but the segments mainly involved are

C6, 7, 8. The degree of paralysis of pectoralis major may be helpful in gauging the extent of a brachial plexus injury (p. 125).

Action. The muscle is a medial rotator of the arm and, in combination with the muscles of the posterior axillary fold, particularly the latissimus dorsi, a powerful *adductor of the arm*. It is especially well developed in climbing and flying animals. The sternocostal fibres are the chief adductors; the clavicular head assists in flexion at the shoulder joint. With the upper limb fixed in abduction the muscle is a useful accessory muscle of inspiration, drawing the ribs upwards towards the humerus.

Test. For the clavicular head the arm is abducted to 90° or more and the patient pushes the arm forwards against resistance. For the sternocostal head the arm is abducted to 60° and then adducted against resistance. The contracting heads can be seen and felt.

Pectoralis minor

In contrast to pectoralis major whose costal fibres arise from cartilage, this small triangular muscle arises from bone, usually from the third, fourth and fifth ribs under cover of pectoralis major (Fig. 2.12). Variations in this origin are common, the muscle being often prefixed

(from the second, third and fourth ribs) and occasionally postfixed (from the fourth, fifth and sixth ribs). The insertion is by a short thick tendon into the medial border and upper surface of the coracoid process of the scapula (not to the tip of the process, which is fully occupied by biceps and coracobrachialis).

Of no great functional significance, the muscle is an important landmark, being the guide to the underlying axillary artery (p. 65) and the cords of the brachial plexus (p. 68).

Nerve supply. By both pectoral nerves (C6, 7, 8).

Action. It assists serratus anterior in protraction of the scapula, keeping the anterior (glenoid) angle in apposition with the chest wall as the vertebral border is drawn forwards by serratus anterior. The muscle is elongated when the scapula rotates in full abduction of the arm; its subsequent contraction assists gravity in restoring the scapula to the rest position.

Subclavius

This small and unimportant muscle arises from the costochondral junction of the first rib and is inserted into the subclavian groove on the inferior surface of the clavicle. The muscle thus lies almost horizontally. It is enclosed by the upper attachment of the clavipectoral fascia (Fig. 2.3).

Nerve supply. By its own nerve from the upper trunk of the brachial plexus (C5, 6); it runs down from the point of formation of the upper trunk to enter the posterior surface of the muscle.

Action. It assists in stabilizing the clavicle in movements of the pectoral girdle. It may prevent the jagged ends of a fractured clavicle from damaging the adjacent subclavian vein.

The **clavipectoral fascia** is a sheet of membrane filling in the space between the clavicle and pectoralis minor, limited laterally by the coracoid process and passing medially to fuse with the external intercostal membrane of the upper two spaces. It splits above to enclose subclavius, being attached to the anterior and posterior ridges which limit the subclavian groove on the under surface of the clavicle. These two layers reappear above the clavicle as the lower attachment of the investing layer of deep cervical fascia (p. 421), but there is no physical continuity between them, each fascia being firmly attached to the clavicle above and below, not passing over the bone (Fig. 2.3).

At the lower border of subclavius the two layers fuse and may form a well-developed band, the *costocoracoid ligament*, stretching from the knuckle of the coracoid to the first costochondral junction. From this ligament the

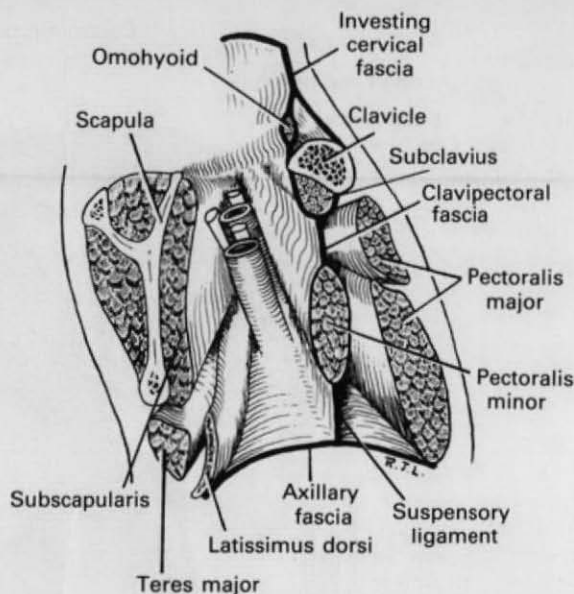


Fig. 2.3 Vertical section of the left axilla, looking laterally towards the arm. The clavipectoral fascia encloses subclavius and pectoralis minor, below which it becomes the suspensory ligament of the axilla, joining the axillary fascia which arches upwards between pectoralis major and latissimus dorsi. The neurovascular bundle of the upper limb lies between the anterior and posterior axillary walls.

fascia stretches as a loosely felted membrane to the upper border of pectoralis minor, which muscle is enclosed by the splitting of the membrane into anterior and posterior leaves. These leaves are very thin and amount to little more than the epimysium of the muscle. They rejoin below pectoralis minor to extend downwards as the **suspensory ligament of the axilla** (Fig. 2.3). The latter is attached to the axillary fascia over the floor of the axilla, and by its tension maintains the axillary hollow.

The clavipectoral fascia is almost covered by pectoralis major and the anterior fibres of the deltoid, but a small extent appears in the **infraclavicular fossa** in the interval between these two muscles. In this situation it is pierced by four structures — two passing inwards, two passing outwards. Passing inwards are lymphatics from the infraclavicular nodes to the apical nodes of the axilla, and the cephalic vein; passing outwards are the thoracoacromial vessels and the lateral pectoral nerve. The thoracoacromial artery has four main branches of distribution: clavicular, humeral, acromial and pectoral. These frequently pierce the fascia separately; their corresponding veins, however, join the cephalic vein anterior to the fascia. This is a characteristic arrangement in anatomy (compare, for

example, with branches of the femoral artery below the groin, piercing the fascia lata separately from the veins which join the great saphenous vein before the latter pierces the cribriform fascia, p. 147).

Trapezius

This large flat muscle, the most superficial of the upper part of the back, arises in the midline from skull to lower thorax and converges on the outer part of the pectoral girdle, which it rotates upwards. Its origin extends from the medial third of the superior nuchal line to the spine of C7 vertebra, finding attachment to the ligamentum nuchae between the external occipital protuberance and the vertebral spine. Below this the origin extends along the spinous processes and supraspinous ligaments of all 12 thoracic vertebrae. Opposite the upper thoracic spines the muscle shows a triangular aponeurotic area, which makes a diamond with that of the opposite side (Fig. 2.6).

The occipital fibres are inserted into the lateral third of the clavicle at its posterior border; from above downwards the fibres can be traced into their insertion along the medial border of the acromion and the superior lip of the crest of the scapular spine (Fig. 2.16). The part of the muscle which arises from the lowest half-dozen thoracic spines is inserted by a narrow recurved tendon into the medial end of the spine; this tendon slides over the bare area at the base of the spine of the scapula, a bursa intervening (Fig. 2.6).

Nerve supply. From the spinal part of the accessory nerve (C1–5 or 6) and branches from the cervical plexus (C3 and 4), the latter normally being only proprioceptive. These nerves cross the posterior triangle to enter the deep surface of trapezius, although in some cases they do appear to contain motor fibres (p. 427). The accessory nerve can be distinguished from the cervical branches by the fact that it emerges from within the substance of sternocleidomastoid; the cervical nerves emerge from *behind* sternocleidomastoid.

Action. All fibres help to retract the scapula (pull it towards the midline), while the upper and lower fibres are important in scapular rotation — tilting the glenoid cavity upwards, an essential component of abduction of the shoulder. In this action some upper fibres elevate the acromion while some lower fibres depress the medial end of the spine, like turning a wing nut (Fig. 2.4), and in this they are strongly assisted by the lowest four digitations of serratus anterior (p. 60). The upper fibres can elevate the whole scapula (shrug the shoulder) or prevent its depression (as when carrying something heavy). They can also produce lateral flexion



Fig. 2.4 Rotation of the scapula. The upper and lower parts of trapezius pull on the scapular spine in different directions, twisting it like a wing-nut, while serratus anterior pulls on the inferior angle.

of the neck, but acting with the upper fibres of the opposite side they can extend the neck.

Test. The shoulder is shrugged against resistance and the upper border of the muscle is seen and felt. If paralysed, the combined actions of levator scapulae and serratus anterior may compensate.

Latissimus dorsi

This muscle, covering such a large area of the back, is characterized by its very wide origin and its very narrow insertion. It is a derivative of the upper limb myotomes, and so is supplied by a branch of the brachial plexus.

The origin commences above, at the spine of T7 vertebra, and extends downwards along the spinous processes and supraspinous ligaments of all the lumbar and sacral vertebrae. Fleishy in the thoracic portion, the origin becomes aponeurotic in the lumbar and sacral region, and fuses with the posterior layer of the lumbar fascia, by which layer it also arises from the central ridge on the posterior part of the crest of the ilium (Fig. 2.5). Lateral to this it arises by flesh from the posterior third of the outer lip of the iliac crest. The upper border of the flat sheet of muscle runs horizontally, and is covered by the lower triangular part of trapezius, and flows over the inferior angle of the scapula, from which a few fibres arise to join the muscle (Fig. 2.6). The lateral border of the muscle, thicker and more rounded than its thin upper border, runs vertically upwards, being reinforced by four slips from the lowest four ribs, whose fibres of origin interdigitate with those of the external oblique. This lateral border of latissimus dorsi forms a boundary of the lumbar triangle (Fig. 2.5 and p. 296). The muscle converges towards the posterior axillary fold, of which it forms the

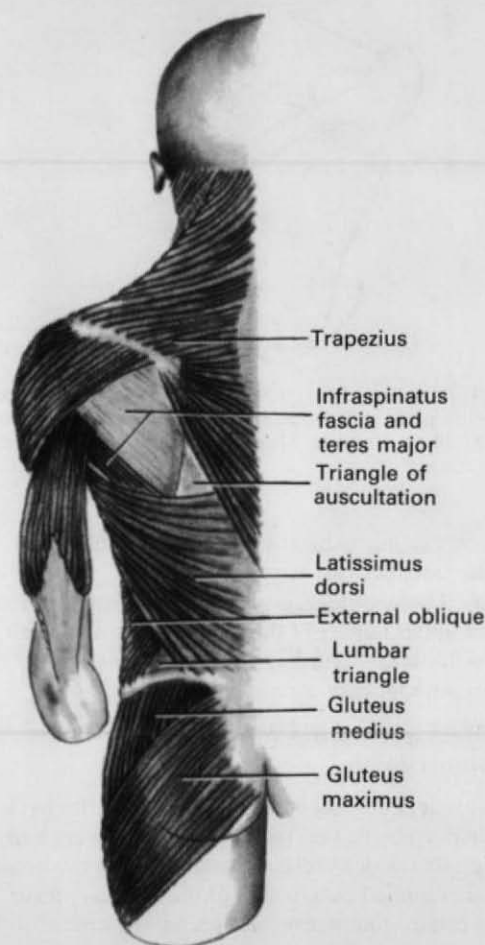


Fig. 2.5 Muscles of the left side of the back of the trunk.

lower border. The fibres, sweeping spirally around the lower border of teres major, are replaced by a flattened tendon about 2.5 cm broad which is inserted into the floor of the intertubercular groove (Fig. 2.10). The surfaces of the muscle, anterior and posterior, are reversed at the insertion of the tendon as a result of the spiral turn around teres major. This glistening white tendon contrasts with adjacent muscle and is a useful landmark in the lower posterior wall of the axilla.

Nerve supply. By the thoracodorsal nerve (C6, 7, 8) from the posterior cord of the brachial plexus. It is vulnerable in operations on the axilla, for in its course down the posterior wall it slopes forwards to enter the medial surface of the muscle just behind its anterior border (Fig. 2.15). The latissimus dorsi is developed in the extensor compartment of the limb and migrates to its wide attachment on the trunk, taking its nerve with it.

Action. It extends the shoulder joint and medially rotates the humerus (e.g. folding the arms behind the back, or scratching the opposite scapula), but in combination with pectoralis major it is a powerful adductor. Especially used in restoring the upper limb from abduction above the shoulder, it is essentially the climbing muscle.

Its costal fibres of origin can assist in deep inspiration, elevating the lower four ribs towards the fixed humerus. But the remainder of the muscle, sweeping from the vertebral column around the convexity of the posterolateral chest wall, compresses the lower thorax and is an accessory muscle of *expiration*. These fibres sometimes become sore after prolonged attacks of severe coughing.

In spinal injury the muscle may move the pelvis and trunk, it is the only muscle of the upper limb to have a pelvic attachment (via the lumbar fascia). A recent innovation is its use in *cardiomyoplasty*: the muscle is wrapped round the heart with its nerve supply intact and stimulated by a pulse generator so that it can act as a 'biological assist device'.

Test. The arm is abducted to a right angle and then adducted against resistance; the anterior border of the muscle below the posterior axillary fold can be seen and felt. The muscle can also be felt to contract here when the patient coughs.

Triangle of auscultation

The upper horizontal border of the muscle forms with the vertebral border of the scapula and the lateral border of trapezius the triangle of auscultation (Fig. 2.5). A fascial sheet, which encloses latissimus dorsi and the rhomboids, floors in the triangle superficial to the seventh rib and sixth and seventh intercostal spaces. The triangle is so named because deep to it, on the left side, is the cardiac orifice of the stomach, where the splash of swallowed liquids was timed in cases of oesophageal obstruction in preradiological days.

Rhomboid major and minor

Rhomboid major arises from four vertebral spines (T2–5), and the intervening supraspinous ligaments. Its insertion into the scapula (Fig. 2.6) extends from the inferior angle to the *upper* part of the triangular area at the base of the scapular spine; a fibrous arch receives the fibres of the muscle between these two points. The fibrous arch is often only loosely attached to the vertebral border of the scapula except at its ends (like the bony origin of levator ani, p. 375).

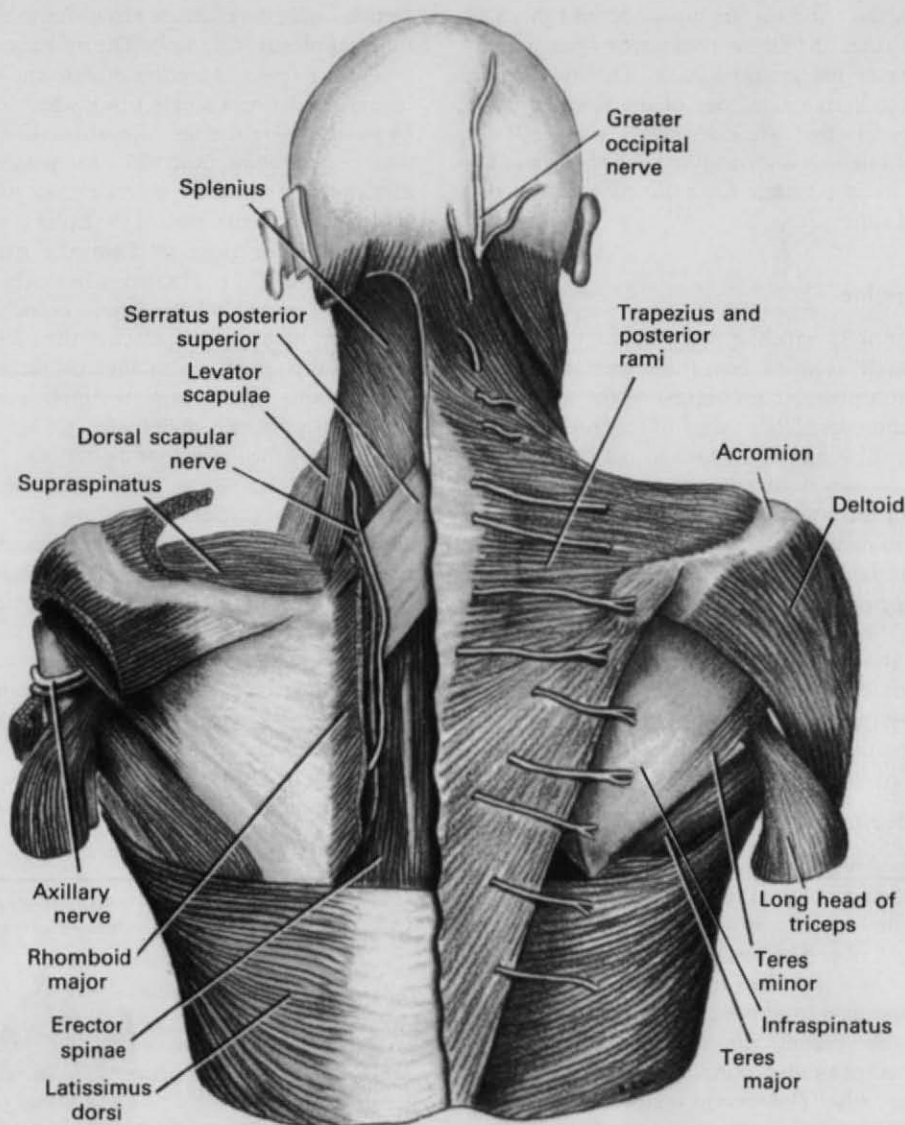


Fig. 2.6 Muscles of the pectoral girdle from behind. On the left most of trapezius, deltoid and the rhomboids have been removed to show the dorsal scapular nerve accompanied by the (unlabelled) dorsal scapular artery, and the axillary nerve with the (unlabelled) posterior circumflex humeral artery.

Rhomboid minor is a narrow ribbon of muscle parallel with the above, arising from two vertebral spines (C7, T1) and inserted into the medial border of the scapula above the triangular area and below the attachment of levator scapulae (Fig. 2.16).

Nerve supplies. By the dorsal scapular nerve (nerve to the rhomboids) from the C5 root of the brachial plexus which passes through scalenus medius, runs down deep to levator scapulae (which it supplies) and

lies on the serratus posterior superior muscle to the medial side of the descending branch of the transverse cervical artery (Fig. 2.6). It supplies each rhomboid on the deep surface.

Actions. The rhomboids draw the vertebral border of the scapula medially and upwards. They are antagonists to the rotatory action of trapezius; they contract with trapezius in squaring the shoulders, i.e. retracting the scapula.

Test. With the hand on the hip or behind the back the patient pushes the elbow backwards against resistance and braces the shoulder back. The muscles are palpated at the vertebral border of the scapula; being deep to trapezius they are not always visible. If the rhomboids of one side are paralysed the scapula of the affected side remains farther from the midline than that of the normal side.

Levator scapulae

A strap-like muscle which appears in the floor of the posterior triangle, it arises from the posterior tubercles (i.e. from true transverse processes) of the upper four cervical vertebrae by slender slips of tendon. The four slips fuse into the long belly, which usually is longitudinally split. It courses downwards to be inserted into the upper angle of the scapula. It may not be derived from the upper limb myotomes, but from the external of the three layers of the body wall (p. 242).

Nerve supply. From the cervical plexus (C3, 4, anterior rami), reinforced by the dorsal scapular nerve (nerve to the rhomboids, C5).

Action. Similar to the rhomboid muscles (above). Like the upper part of trapezius, it can laterally rotate the neck, or (with its opposite fellow) extend the neck.

Serratus anterior

This is a broad sheet of thick muscle (Fig. 2.15) which clothes the side wall of the thorax and forms the medial wall of the axilla. It arises by a series of digitations from the upper eight ribs. The first digitation, which appears in the posterior triangle, arises from the outer border of the first rib and also from the rough impression which characterizes the second rib. Over its upper border passes the neurovascular bundle from the posterior triangle to the axilla. The second digitation arises from the second rib and is inserted, together with the first, into the upper angle of the scapula. (This part of the muscle is innervated from C5). The third and fourth digitations arise from the third and fourth ribs and form a thin sheet of muscle which spreads out to be inserted into the length of the costal surface of the scapula along a narrow strip at its vertebral border. (This part is innervated from C6.) The lower four digitations arise from the fifth, sixth, seventh and eighth ribs, interdigitating with the slips of origin of external oblique at the anterior angles of the ribs. Thick, fleshy muscles, they converge strongly on the inferior angle of the scapula. (They are supplied by C7.) The muscle is covered by a strong well-developed fascia.

Nerve supply. By the long thoracic nerve (nerve to

serratus anterior) which arises from the roots of the brachial plexus (C5, 6, 7). The branches from C5 and 6 join in the scalenus medius muscle and emerge from its lateral border as a single trunk which enters the axilla by passing over the first digitation of serratus anterior. The contribution from C7 also passes over the first digitation of serratus anterior and joins the former nerve on the medial wall of the axilla (i.e. on the surface of serratus anterior) to form the nerve to serratus anterior (Fig. 2.7). The nerve lies behind the midaxillary line (i.e. behind the lateral branches of the intercostal arteries) on the surface of the muscle (Fig. 2.15), deep to the fascia, and is thus protected in operations on the axilla. The muscle is supplied segmentally; C5 into the upper two digitations, C6 into the next two, and C7 into the lower four digitations.

Action. The whole muscle contracting en masse protracts the scapula (punching and pushing), thus effectively elongating the upper limb. A further highly important action is that of the lower four digitations, which powerfully assist trapezius in rotating the scapula laterally and upwards in raising the arm above the level of the shoulder. In this action it is a more powerful rotator than trapezius. In all positions the muscle keeps the vertebral border of the scapula in firm apposition with the chest wall.

Test. The outstretched hand is pushed against a wall. A number of digitations should be seen and felt on

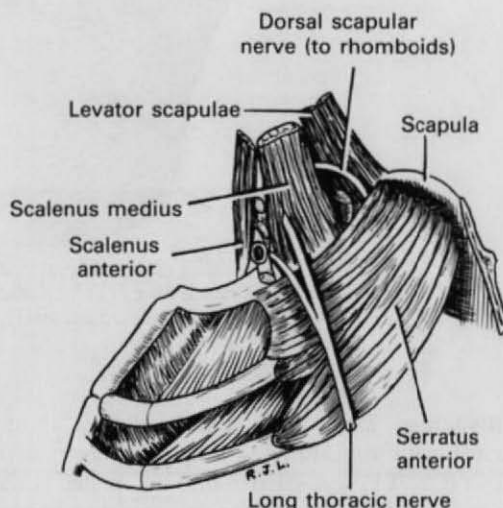


Fig. 2.7 Left long thoracic nerve (to serratus anterior). The branches from C5 and 6 fuse within scalenus medius and emerge as a single trunk which is joined in the axilla over the first digitation of serratus anterior by the branch from C7. The second rib gives origin to half of the first digitation and all the second digitation of the muscle.

the lateral chest wall. Paralysis results in 'winged scapula', where the vertebral border becomes prominently raised off the posterior chest wall.

JOINTS OF THE PECTORAL GIRDLE

Sternoclavicular joint

This is a synovial joint, separated into two cavities by an intervening disc of fibrocartilage. Although synovial, it is atypical since the bony surfaces are covered by fibrocartilage, not the usual hyaline variety. The articular surface on the manubrium sterni is set at an angle of 45° with the perpendicular, and is markedly concave from above downwards. The articular surface on the sternal end of the clavicle, flattened or slightly concave, is continued over the inferior surface of the shaft in a high percentage of cases, for articulation with the first costal cartilage. The sternal end of the clavicle projects well above the upper margin of the manubrial facet (Fig. 2.8) so that only about the lower half of the clavicular articular surface lies opposite the sternal articular facet.

The **capsule** invests the articular surfaces like a sleeve. To this capsule the **articular disc** is attached, thus dividing the joint into two separate cavities. Rarely the disc is perforated. The disc is also firmly attached to the medial end of the clavicle above and behind, and to the first costal cartilage below, as though to restrain the sternal end of the clavicle from tilting upwards and being displaced medially as the weight of the arm depresses the acromial end. The capsule is thickened in front and behind as the **anterior** and **posterior sternoclavicular ligaments**, and it is weaker at the front (anterior dislocation is commoner than posterior, though both are rare).

The **interclavicular ligament** joins the upper borders of the sternal ends of the two clavicles and is itself attached to the suprasternal (jugular) notch. The **costoclavicular ligament** binds the clavicle to the first costal cartilage and the adjacent end of the first rib, just lateral to the joint; it is an accessory ligament thereof. It is in two laminae (usually separated by a bursa), which are attached to the anterior and posterior lips of the ligamentous impression on the clavicle. The fibres of the anterior lamina run upwards and laterally, and those of the posterior lamina upwards and medially (these are the same directions as those of the external and internal intercostal muscles). The ligament is very strong and is the major stabilizing factor of the sternoclavicular joint.

Nerve supply. The medial supraclavicular nerves (C3, 4) from the cervical plexus give articular branches to the capsule and ligaments.

Movements. The fulcrum of movements at this joint is *not the sternal end of the clavicle*, but the costoclavicular ligament. As the lateral end of the clavicle moves, its medial end moves in the opposite direction. This can be readily demonstrated by simple palpation (feel your own!). Elevate the acromial end by shrugging the shoulder; the sternal end moves down. Only in complete elevation of the acromial end, as in full abduction of the arm, when the *medial* end of the clavicle can be depressed no further, is the ligament put on full stretch. Depress the acromial end of the clavicle by drooping the shoulder; the sternal end moves up. Upward movement of the sternal end is halted by the interclavicular ligament, and especially by the intra-articular disc (Fig. 2.8). Protrude the acromial end of the clavicle by hunching the shoulders forward; the sternal end moves back. Retract the acromial end by squaring the shoulders; the sternal end moves forward.

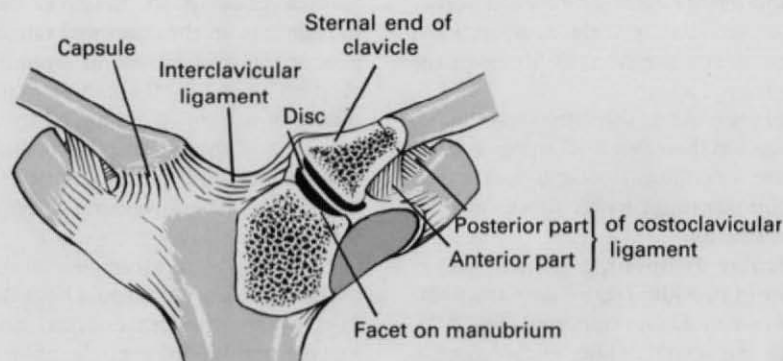


Fig. 2.8 Left sternoclavicular joint, sectioned and viewed from the front. The clavicle extends well above the bony socket of the manubrium, and is bound down by the disc and costoclavicular ligament.

The clavicle moves about the costoclavicular ligament like a see-saw in both the horizontal and the coronal planes. In shrugging the shoulder the clavicle moves *on* the disc; in protracting the scapula, the clavicle moves *with* the disc.

A further movement takes place at the sternoclavicular joint, namely rotation. Rotation of the clavicle is passive; there are no rotator muscles. It is produced by rotation of the scapula and transmitted to the clavicle through the coracoclavicular ligaments (see below). Palpate the forward convexity of the clavicle. Flex the arm in the sagittal plane and continue upwards in this plane to full abduction above the head. Restore the arm and carry it back in the sagittal plane into full extension. The rotation of the clavicle can be easily felt—it amounts, in fact, to some 40° .

Elevation and depression of the acromial end of the clavicle, resulting in movements downwards and upwards respectively of the sternal end, cause movement between the clavicle and the disc. Forward and backward movements in the horizontal plane result in movements between the fibrocartilage and manubrium, the former moving with the sternal end of the clavicle. Similarly, in rotary movements (abduction of the arm above the head) the disc moves with the clavicle.

The *stability* of the joint is maintained by the ligaments, most especially the costoclavicular ligament. It takes all strain off the joint, transmitting stress from clavicle to first costal cartilage. The latter is itself immovably fixed to the manubrium by a primary cartilaginous joint (p. 243). Dislocation is unusual; the clavicle breaks in preference.

Acromioclavicular joint

This is a synovial joint between the overhanging lateral end of the clavicle and the underhanging medial border of the acromion. The articulating surfaces are covered (like those of the sternoclavicular joint) by fibrocartilage (so it is an atypical synovial joint).

A sleevelike capsule surrounds the articular surfaces; it is not strong, but on top there is a thickening of fibres which constitutes the acromioclavicular ligament. An incomplete disc of fibrocartilage hangs down into the upper part of the joint cavity.

The **coracoclavicular ligament**, extremely strong, is the principal factor in providing stability to the joint. It consists of two parts, conoid and trapezoid (Fig. 2.9). Examine the clavicle and scapula. The *conoid ligament*, an inverted cone, extends upwards from the knuckle of the coracoid to a wider attachment around the conoid tubercle, on the under surface of the clavicle

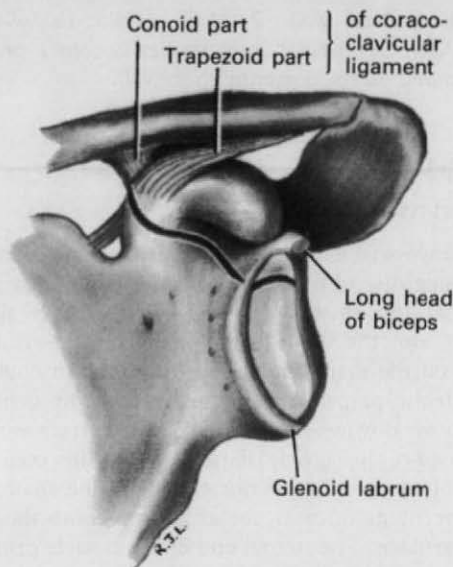


Fig. 2.9 Glenoid cavity of the left scapula and the coracoclavicular ligament. The black line marks the epiphysis between the (dorsal) scapula proper and the (ventral) coracoid bone. The glenoid labrum continues above into the long head of biceps. The trapezoid part of the coracoclavicular ligament lies in front of and lateral to the conoid part.

(Fig. 2.58). The *trapezoid ligament* is attached to the ridge of the same name on the upper surface of the coracoid process and extends laterally, in an almost *horizontal plane*, to the trapezoid ridge on the under surface of the clavicle (Fig. 2.58).

Nerve supply. By lateral supraclavicular nerves (C4) from the cervical plexus.

Movements. These are passive (compare with the superior tibiofibular joint, p. 189); no muscle connects the bones to move the joint. Muscles which move the scapula cause it to move on the clavicle. Scapular movements on the chest wall fall into three groups: (1) protraction and retraction around the chest wall, (2) rotation, and (3) elevation or depression. These basic movements can be combined in varying proportions, and each of these transmits, through ligaments, *corresponding movements to the clavicle*. All movements of the scapula involve movements in the joint at either end of the clavicle.

Horizontally, in protraction and retraction of the tip of the shoulder, the scapula hugs the thoracic wall, held to it by serratus anterior and pectoralis minor. The scapula moves in a circle of a shorter radius (i.e. the radius of the upper thorax) than the length of the clavicle. Hence movement takes place between the acromion and the fibrocartilage. The axis of this

movement is vertical and passes through the conoid ligament. The acromion glides to and fro on the tip of the clavicle.

In abduction of the arm the scapula does not retain its position relative to the clavicle but rotates around the conoid ligament as it swings forwards on the chest wall, and movement takes place between the fibrocartilage and the clavicle. The axis of scapular rotation passes through the conoid ligament and the acromioclavicular joint; the scapula swings to and fro like a pendulum below these two fixed points on the clavicle. The total range of scapular rotation on the chest wall is about 60°, but only 20° of this occurs between the scapula and the clavicle. The coracoclavicular ligaments are then taut, and transmit the rotating force to the clavicle, whose rotation then accounts for the remainder of scapular rotation on the chest wall. In both movements at this joint the fulcrum around which the scapula swings is the coracoclavicular ligament.

Elevation (shrugging the shoulders) is produced by the upper fibres of trapezius together with levator scapulae and the rhomboids, mutually neutralizing their rotatory effects. Depression of the scapula is produced by the lower fibres of trapezius and the lateral fibres of latissimus dorsi. Elevation and depression move the medial end of the clavicle (see above), but they scarcely move the acromioclavicular joint.

The stability of the joint is provided by the coracoclavicular ligament. The scapula and upper limb hang suspended from the clavicle by the conoid ligament (assisted by the deltoid, biceps and triceps muscles). Forces transmitted medially from the upper limb to the glenoid cavity are transmitted from scapula to clavicle by the trapezoid ligament and from clavicle to first rib by the costoclavicular ligament. Thus a fall on outstretched hand or elbow puts no strain on either end of the clavicle at the joints. If the clavicle fractures as a result, it always does so between these ligaments. Falls on the shoulder may dislocate the acromioclavicular joint, forcing the acromion under the clavicle and tearing the coracoclavicular ligament.

PART 2

AXILLA

The **axilla** is the space between the upper arm and the side of the thorax, bounded in front and behind by the axillary folds, communicating above with the posterior triangle of the neck and containing neurovascular structures, including lymph nodes, for the upper limb and

the side wall of the thorax. Its floor is the axillary fascia extending from the fascia over the serratus anterior to the deep fascia of the arm, attached in front and behind to the margins of the axillary folds, and supported by the suspensory ligament (Fig. 2.3) from the lower border of pectoralis minor. Its **anterior wall** is completed by pectoralis major, pectoralis minor, subclavius and the clavipectoral fascia; these have been described on page 54. The **posterior wall** extends lower; it is formed by subscapularis and teres major (see below), with the tendon of latissimus dorsi winding around the latter muscle. The **medial wall** is formed by the upper part of serratus anterior, the lower limit of the axilla being defined as the level of the fourth rib. The anterior and posterior walls converge laterally to the lips of the intertubercular groove of the humerus (Fig. 2.10).

The **apex** is bounded by clavicle, scapula and the outer border of the first rib; it is the channel of communication between axilla and posterior triangle.

The axilla virtually does not exist when the arm is fully abducted. Its folds disappear as their muscles run tangentially along the humerus, and the axillary hollow is replaced by a bulge.

Subscapularis

This arises from the medial four-fifths of the costal surface of the scapula, from the intermuscular septa which raise bony ridges on this surface and from the concave axillary border of the scapula up to the infraglenoid tubercle (Fig. 2.10). The multipennate muscle converges over the bare area at the lateral angle of the scapula, its musculotendinous fibres sliding over this bone and separated from it by a bursa. This **subscapular bursa** (Fig. 2.11) extends laterally and communicates with the cavity of the shoulder joint through a gap in the anterior part of its capsule between the superior and middle glenohumeral ligaments. Lateral to this the tendon fuses with the capsule of the shoulder joint and is inserted into the lesser tuberosity of the humerus and the medial lip of its intertubercular groove for half an inch below (Fig. 2.10). The muscle is covered by a dense fascia which is attached to the scapula at the margins of its origin.

Nerve supply. By the upper and lower subscapular nerves (C5, 6) from the posterior cord of the brachial plexus.

Action. With the other short scapular muscles the subscapularis gives stability to the shoulder joint, assisting in fixation of the upper end of the humerus during movements of elbow, wrist, and hand. Acting as a prime mover, it is a medial rotator of the humerus.

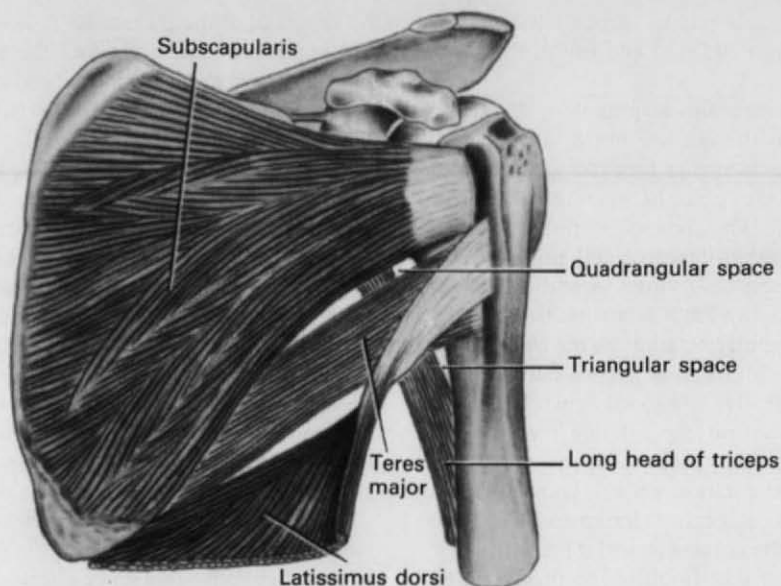


Fig. 2.10 Muscles of the posterior wall of the left axilla, from the front. The long head of triceps passes behind teres major, making adjacent to the humerus a quadrangular space (for the axillary nerve) and a triangular space (for the radial nerve). Compare with Figure 2.16.

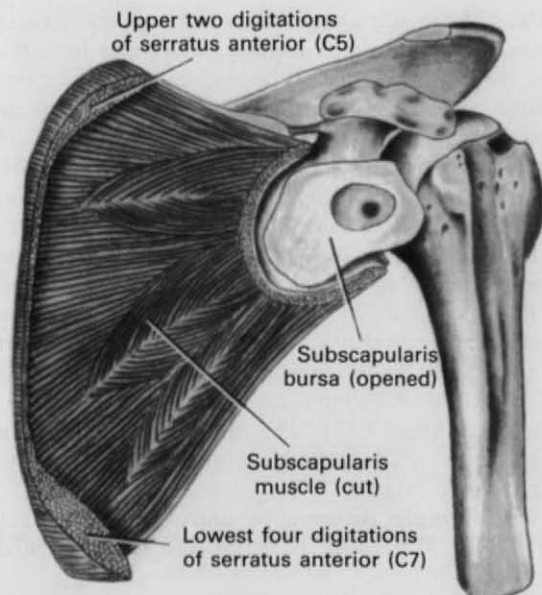


Fig. 2.11 Left subscapularis bursa, exposed by removing part of subscapularis and showing the communication with the shoulder joint cavity. Compare with Figure 2.10. The insertion of serratus anterior is also shown, with the segmental innervation of muscle fibres.

There is no satisfactory test for the muscle, since its action is difficult to differentiate from other medial rotators.

Teres major

This is an offspring of subscapularis. It has migrated around to the dorsal surface of the scapula, where it arises from an oval area on the lateral side of the inferior angle. It runs edge to edge with the lower border of its parent subscapularis, and is inserted in continuity with it into the medial lip of the intertubercular groove. The ribbon-like tendon of latissimus dorsi winds around its lower border and comes to lie in front of the upper part of the muscle at its insertion (Fig. 2.10).

Nerve supply. By the lower subscapular nerve (C5, 6), which supplies its parent subscapularis, and lies in the angle between the subscapular and circumflex scapular arteries, entering the anterior surface of the muscle.

Action. It assists the other short muscles in steadying the upper end of the humerus in movements at the periphery of the limb; acting alone it is an adductor and medial rotator of the humerus at the shoulder joint, and helps to extend the flexed arm. With teres minor it holds down the upper end of the humerus as deltoid pulls up the bone into abduction (Fig. 2.20). Its tendon

can be transplanted posteriorly to provide lateral rotation.

Test. The abducted arm is adducted against resistance, and the muscle is seen and felt from behind the posterior axillary fold.

The **quadrangular space** lies between subscapularis and teres major in the posterior wall of the axilla. It is bounded laterally by the humerus and medially by the long head of triceps (Fig. 2.10). It transmits the axillary nerve, with the posterior circumflex humeral artery and vein inferiorly. Viewed from behind, the quadrangular space is bounded above by the teres minor muscle; its three other boundaries are the same (Fig. 2.16). The **triangular space**, below teres major and between the humerus and the long head of triceps, transmits the radial nerve and profunda brachii vessels.

CONTENTS OF THE AXILLA

The axilla transmits the neurovascular bundle from the neck to the upper limb.

The three cords of the brachial plexus are formed behind the clavicle and enter the upper part of the axilla

above the artery. The cords approach the artery and embrace its second part (Fig. 2.12), the part which lies under cover of the pectoralis minor, lying medial, lateral and posterior to it in the manner indicated by their names. The axillary vein lies throughout on the medial side of the artery and nerves. In the fibrofatty areolar tissue of the axilla lie several groups of lymph nodes.

Axillary artery

This is the continuation of the third part of the subclavian artery. It enters the apex of the axilla by passing over the first digitation of serratus anterior, at the outer border of the first rib, behind the midpoint of the clavicle. It is invested in fascia, the *axillary sheath*, projected down from the prevertebral fascia (Fig. 6.6, p. 441). At the lower border of teres major it becomes the brachial artery. It is conveniently divided into three parts by pectoralis minor: the part above, the part behind, and the part below. The second part, that *behind* the muscle, is readily recognized in a dissected axilla, where pectoralis minor has been removed, as that part of the artery which is clasped by the three cords of the plexus laterally, medially and posteriorly (Fig. 2.12).

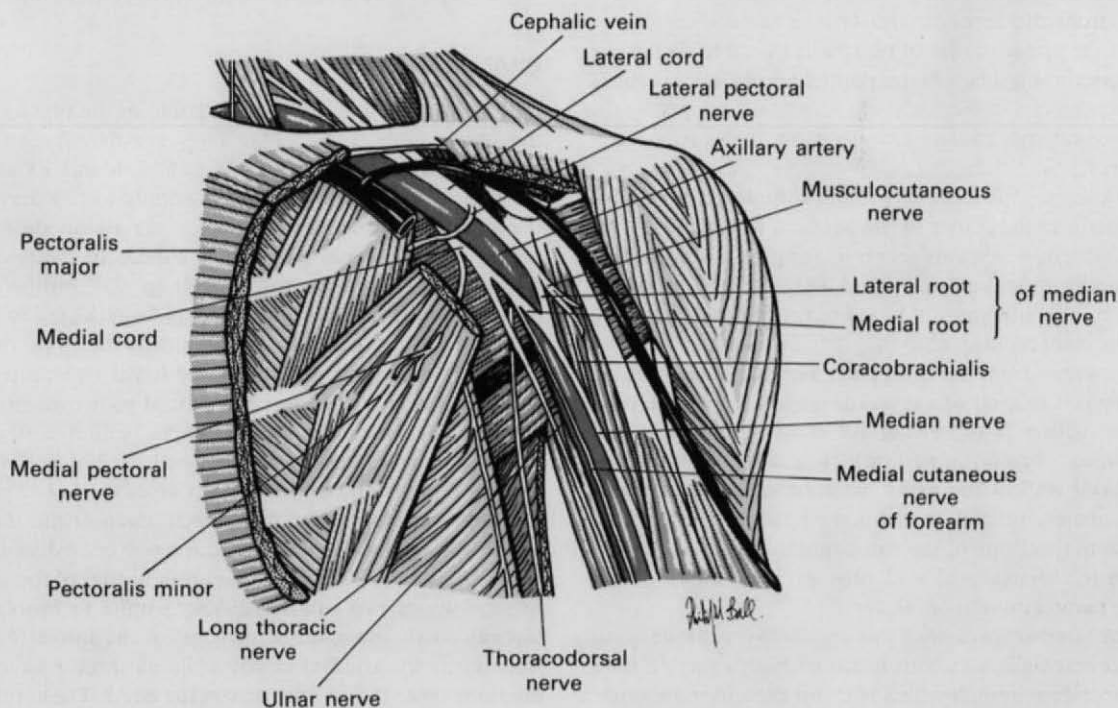


Fig. 2.12 Left axilla and brachial plexus from the front, after removal of much of pectoralis major and minor and the axillary vein. The medial cutaneous nerve of the forearm lies in front of the ulnar nerve medial to the axillary artery. The median nerve is in front of the artery, and laterally the musculocutaneous nerve enters coracobrachialis.

The shape of the artery depends upon the position of the arm. With the arm at the side the artery has a bold curve with its convexity lateral, and its third part is clasped by the two heads of the median nerve. With the arm laterally rotated and abducted, as in operations upon the axilla, the artery pursues a straight course and the two heads of the median nerve lie loosely upon its third part.

The *surface marking* of the artery, when the arm is by the side, is indicated by a curved line from the middle of the clavicle running below the coracoid process to the groove behind coracobrachialis.

Surgical approach. The first part of the artery can be exposed by splitting the clavicular head of pectoralis major in the line of its fibres and incising the clavipectoral fascia. The rest of the artery is approached through the axilla, above the posterior fold in the groove between coracobrachialis and the long head of triceps.

Branches. Apart from some inconstant superior thoracic twigs to the upper axillary walls, it may be said that the first part has one branch, the second part two, and the third part three branches.

The *superior thoracic artery*, from the first part, runs forwards to supply both pectoral muscles.

The thoracoacromial and lateral thoracic arteries arise from the second part. The *thoracoacromial artery* skirts the upper border of pectoralis minor to pierce the clavipectoral fascia, often separately in its four terminal branches (clavicular, deltoid, acromial and pectoral). These branches radiate away at right angles from each other.

The *lateral thoracic artery* follows the lower border of pectoralis minor, close to the pectoral lymph nodes, on the fascia over serratus anterior, supplying branches to pectoralis minor and major and, in the female, being an important contributor of blood to the breast.

The subscapular and the two circumflex humeral arteries arise from the third part. The *subscapular artery*, the largest branch of the axillary, runs down the posterior axillary wall, giving off a dorsal branch, the *circumflex scapular artery*, which passes through the posterior wall of the axilla between subscapularis and teres major, medial to the long head of the triceps. Distal to this branch, the subscapular artery changes its name to *thoracodorsal*, and runs with the nerve of the same name into latissimus dorsi.

The *anterior circumflex humeral artery* runs deep to coracobrachialis and both heads of biceps (giving here an ascending branch which runs up the intertubercular groove to the long tendon of biceps and the capsule of the shoulder joint), and passes around the surgical neck of the humerus to anastomose with the *posterior*

circumflex humeral artery. This, a much larger branch of the axillary artery, passes through the posterior axillary wall between subscapularis and teres major lateral to the long head of triceps, between it and the humerus (i.e. through the quadrangular space). It is accompanied above by the axillary nerve and, like it, supplies the deltoid. It also gives branches to the long and lateral heads of triceps and the shoulder joint, and anastomoses with the profunda brachii artery.

Axillary vein

The venae comitantes of the brachial artery are joined by the basilic vein above the lower border of the posterior wall of the axilla. They form the **axillary vein**, which courses upwards on the medial side of the axillary artery and leaves the axilla by passing through its apex anterior to the third part of the subclavian artery. Over the upper surface of the first rib, in front of scalenus anterior, it continues as the subclavian vein. Tributaries of the third and second parts of the axillary vein are the same as the branches of the artery. Into the first part (i.e. above pectoralis minor) the cephalic vein enters after having pierced the clavipectoral fascia. There is no axillary sheath around the vein, which is free to expand during times of increased blood flow.

BRACHIAL PLEXUS

Five roots contribute to the formation of the plexus for the upper limb (Fig. 2.13). They are the fibres that remain in the anterior rami of C5, 6, 7, 8 and T1 after these have given their segmental supply to the prevertebral and scalene muscles. They are to divide into anterior and posterior divisions to supply the flexor and extensor compartments respectively (p. 23), but before doing so they unite to form three trunks in the following manner. Of the five roots of the plexus the upper two unite to form the upper trunk, the lower two unite to form the lower trunk, and the central root runs on as the middle trunk. The five **roots** lie behind scalenus anterior muscle and emerge between it and scalenus medius to form the **trunks** which cross the lower part of the posterior triangle of the neck. Each of the three trunks divides into an anterior and a posterior **division** behind the clavicle. Here, at the outer border of the first rib, the upper two anterior divisions unite to form the **lateral cord**, the anterior division of the lower trunk runs on as the **medial cord**, while all three posterior divisions unite to form the **posterior cord**. These three cords enter the axilla above the first part of the artery, approach and embrace its second part, and give off their branches around its third part.

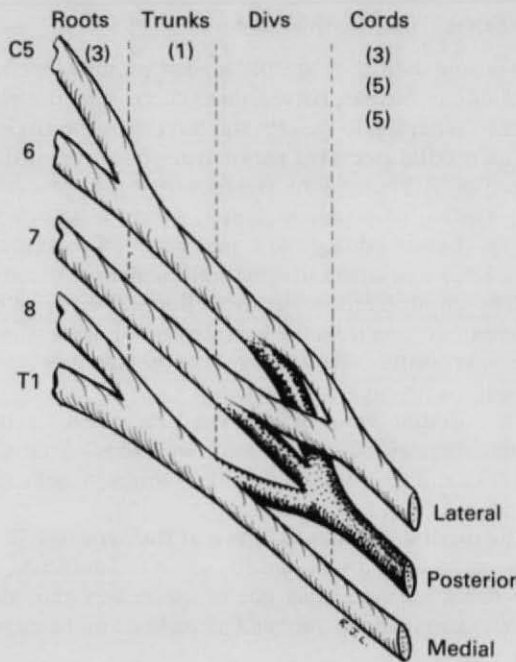


Fig. 2.13 Parts of the left brachial plexus. The anterior rami of C5–T1 nerves form the roots of the plexus (after giving off branches to the prevertebral muscles). The figures in brackets denote the numbers of branches from the constituent parts.

It is important to appreciate the situation of the constituents of the plexus, i.e. roots between scalene muscles, trunks in the triangle, divisions behind the clavicle, and cords in the axilla. The various branches of the plexus (Fig. 2.14) are derived from the roots, trunks and cords; there is none from the divisions. The roots and trunks with their branches form the **supraclavicular part** of the plexus, with the cords and their branches forming the **infraclavicular part**.

When the basic pattern has been learned it is a simple matter to put in the branches of the plexus. They consist of 3 branches from the roots and 3, 5 and 5 from the lateral, medial and posterior cords respectively. The only exception to the 3, 5, 5 rule is in the branch from the trunks. It is only one, the supraclavicular nerve, from the upper trunk, in the posterior triangle. Everywhere else in the plexus the number of branches follows the 3, 5, 5 pattern (Fig. 2.13).

Supraclavicular part — branches from the roots

Three in number, i.e. the dorsal scapular nerve, the nerve to subclavius, and the long thoracic nerve, they arise successively from C5, C5, 6 and C5, 6, 7, and

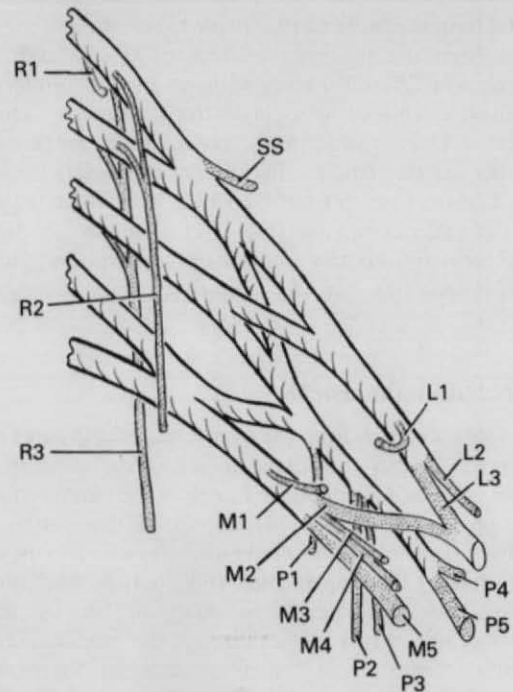


Fig. 2.14 Branches of the left brachial plexus. *Branches of roots:* R1 dorsal scapular (nerve to rhomboids), R2 nerve to subclavius, R3 long thoracic (nerve to serratus anterior).

Branch of upper trunk: SS supraclavicular nerve.

Branches of lateral cord: L1 lateral pectoral nerve, L2 musculocutaneous nerve, L3 lateral root of median nerve.

Branches of medial cord: M1 medial pectoral nerve, M2 medial root of median nerve, M3 medial cutaneous nerve of arm, M4 medial cutaneous nerve of forearm, M5 ulnar nerve.

Branches of posterior cord: P1 upper subscapular nerve, P2 thoracodorsal nerve (to latissimus dorsi), P3 lower subscapular nerve, P4 axillary nerve, P5 radial nerve.

pass downwards behind, in front of, and behind the roots in that order.

The **dorsal scapular nerve** (nerve to the rhomboids) arises from the posterior aspect of C5, enters scalenus medius, appears at its posterior border, and courses downwards beneath levator scapulae, lying on serratus posterior superior. It is accompanied by the dorsal scapular vessels. It supplies both rhomboids on their deep surfaces and usually gives a branch to levator scapulae (Fig. 2.6).

The **nerve to subclavius** arises from the roots of C5 and 6 just as they combine to form the upper trunk (and is often classified as arising from the upper trunk). It passes down in front of the trunks and the subclavian vessels to enter the posterior surface of subclavius. It may carry some aberrant phrenic nerve fibres (p. 427).

The **long thoracic nerve** (nerve to serratus anterior) arises from the posterior aspects of C5, 6 and 7. Branches of C5 and 6 enter scalenus medius, unite in the muscle, emerge as a single trunk from its lateral border and pass down into the axilla. On the surface of serratus anterior (the medial wall of the axilla) this is joined by the branch from C7 which has descended in front of scalenus medius (Fig. 2.7). The nerve passes down posterior to the midaxillary line and supplies serratus anterior muscle segmentally (p. 60 and Fig. 2.15).

Branch from the trunks

The solitary branch from the trunks (unless the nerve to subclavius is also considered to arise from the upper trunk) is the **suprascapular nerve**, which arises from the upper trunk in the lower part of the posterior triangle. It can be seen above the clavicle as a large nerve leaving the upper trunk (Fig. 6.4, p. 430) and passing back and laterally to disappear beneath the border of trapezius. It passes through the suprascapular foramen (beneath the transverse scapular ligament) and supplies supraspinatus, descends lateral to the scapular spine with the suprascapular vessels and supplies infraspinatus and gives a twig to the shoulder joint.

Infraclavicular part — branches from the lateral cord

Three in number, they are the lateral pectoral, musculocutaneous and lateral root of the median nerve.

The **lateral pectoral nerve** pierces the clavipectoral fascia to supply pectoralis major with fibres from C5, 6 and 7 (Fig. 2.12). It communicates across the axillary artery with the medial pectoral nerve and through this communication supplies pectoralis minor. It has no cutaneous branch.

The **musculocutaneous nerve** leaves the lateral cord, runs obliquely downwards and sinks into coracobrachialis (Fig. 2.12), giving a twig of supply to it (C5, 6) before passing through the muscle. Lower down it supplies biceps and brachialis and becomes the lateral cutaneous nerve of the forearm.

The **lateral root of the median nerve** is the continuation of the lateral cord (C5, 6, 7). It is joined by the medial root of the median nerve (from the medial cord, C8 and T1); the two roots embrace the artery (Fig. 2.12) and, when the arm is pulled down to depress the shoulder may, in some cases, compress the vessel. Do not confuse the roots of the plexus with the roots of the median nerve.

Branches from the medial cord

Five in number, they are the medial pectoral, medial head of the median nerve, ulnar nerve, and the two cutaneous nerves, to the arm and forearm respectively.

The **medial pectoral nerve** arises from the medial cord (C8, T1) behind the axillary artery and enters the deep surface of pectoralis minor, giving a branch of supply before doing so, perforates the muscle (Fig. 2.12) and enters the pectoralis major, in which it ends by supplying the lower costal fibres. It is joined by a communication from the lateral pectoral nerve which passes across the axillary artery. Like the lateral pectoral nerve it has no cutaneous branch.

The **medial root of the median nerve** is the continuation of the medial cord, with fibres from C8 and T1, and it crosses the axillary artery to join the lateral root (Fig. 2.12).

The **medial cutaneous nerve of the arm** (C8, T1) is the smallest and most medial of all the branches. It runs down on the medial side of the axillary vein and supplies skin over the front and medial side of the upper arm.

The **medial cutaneous nerve of the forearm** (C8, T1) is a large nerve which runs down between artery and vein in front of the ulnar nerve (Fig. 2.12) and supplies skin over the lower part of the arm and the medial side of the forearm.

The **ulnar nerve** is the largest branch of the medial cord (C7, 8, T1). It runs down between artery and vein behind the medial cutaneous nerve of the forearm (Fig. 2.12), and is the most posterior of the structures which run down the medial side of the flexor compartment of the arm. It receives its C7 fibres as a branch from the lateral cord in over 95%; these fibres are given off in the forearm as the motor branch to flexor carpi ulnaris (p. 90). The ulnar nerve eventually supplies most of the small muscles of the hand (p. 114).

Branches from the posterior cord

Five in number, they are the upper subscapular, thoracodorsal nerve (nerve to latissimus dorsi), lower subscapular, axillary (circumflex), and radial nerves (Fig. 2.15).

The **upper subscapular nerve** is a small nerve (C5, 6) which enters the upper part of subscapularis (Fig. 2.15).

The **thoracodorsal nerve** (nerve to latissimus dorsi C6, 7, 8) is a large nerve which runs down the posterior axillary wall, crosses the lower border of teres major and enters the deep surface of latissimus dorsi, well forward near the border of the muscle (Fig. 2.15). It comes from high up behind the subscapular artery, but

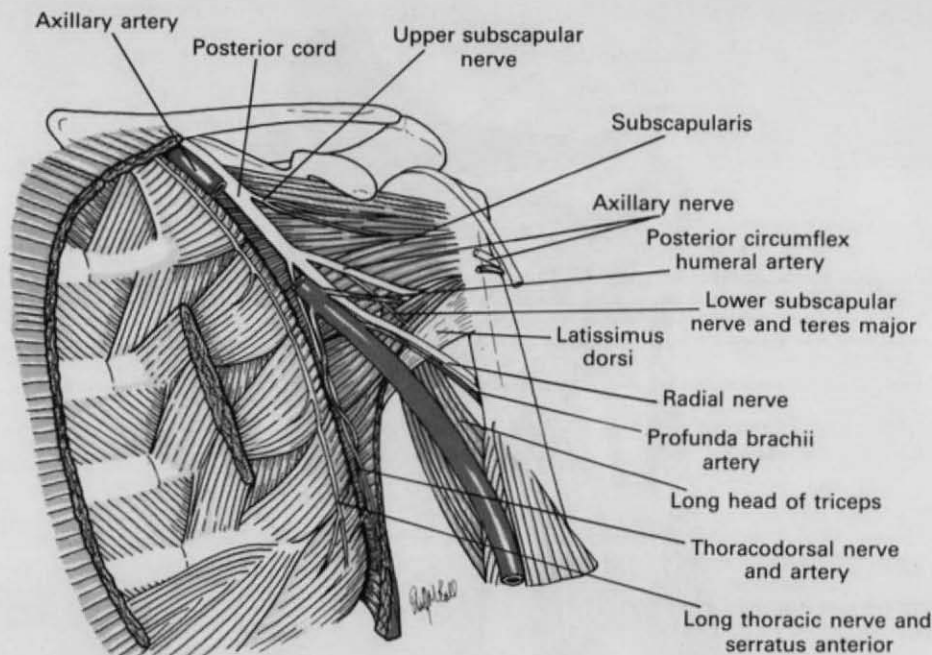


Fig. 2.15 Posterior wall of the left axilla and posterior cord of the brachial plexus. The radial nerve runs in front of the tendon of latissimus dorsi and then passes back through the triangular space. The axillary nerve passes backwards below subscapularis through the quadrangular space.

as it descends to enter the muscle it lies in front of the artery, at this level now called the thoracodorsal artery. It is thrown into prominence in the position of lateral rotation and abduction of the humerus and is thus in danger in operations on the lower axilla.

The **lower subscapular nerve** (C5, 6) is larger than the upper subscapular and supplies the lower part of the subscapularis (Fig. 2.15). It gives a separate twig to teres major, which runs in the angle between the subscapular and circumflex scapular arteries.

The **axillary nerve** (formerly the circumflex nerve) is one of the two large terminal branches of the posterior cord (the other is the radial nerve). The axillary nerve (C5, 6) supplies nothing in the axilla despite its name having been changed from circumflex to axillary. From its origin, which is higher than usually imagined, (Fig. 2.15) it passes backwards between subscapularis and teres major, lateral to the long head of triceps, i.e. through the quadrangular space. Here it lies in contact with the surgical neck of the humerus, just below the capsule of the shoulder joint, with the posterior circumflex humeral vessels below it. Having given a branch to the shoulder joint, it divides into anterior and posterior branches. The *anterior branch* winds round *behind* the humerus in contact with the periosteum and enters the deep surface of the deltoid to supply it

(p. 73); a few terminal twigs pierce the muscle and reach the skin. The *posterior branch* gives off the motor nerve to teres minor, then winds around the posterior border of deltoid and becomes cutaneous. It is here called the *upper lateral cutaneous nerve of the arm*. It supplies a few of the posterior fibres of deltoid.

The **radial nerve** (C5, 6, 7, 8, T1) is the continuation of the posterior cord, and is the largest branch of the whole plexus. It crosses the lower border of the posterior axillary wall, lying on the glistening tendon of latissimus dorsi (Fig. 2.15). It passes out of sight through the triangular space below the lower border of teres major, between the long head of triceps and the humerus (Figs. 2.10 and 2.16). Before disappearing it gives nerves to supply to the long head of triceps, to the medial head by a nerve which accompanies the ulnar nerve along the medial side of the arm, and a cutaneous branch which supplies the skin along the posterior surface of the upper arm (*the posterior cutaneous nerve of the arm*). The radial nerve is important as the nerve of the extensor compartment of the forearm (p. 83).

LYMPH NODES OF THE AXILLA

Contained in the fibrofatty tissue of the axilla are many scattered lymph nodes. The average number is about

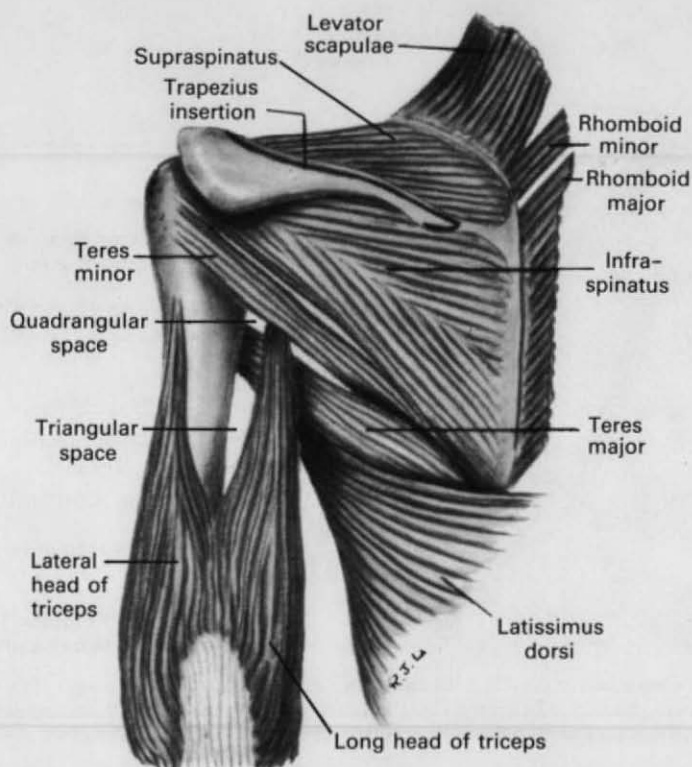


Fig. 2.16 Left scapular muscles from behind. The quadrangular space is bounded by the two teres muscles, the long head of triceps and the humerus. (When viewed from the front, subscapularis replaces teres minor as the upper boundary — see Fig. 2.10) The triangular space through which the radial nerve passes is bounded by teres major, the long head of triceps and the humerus.

35, but there may be over 50. They are usually described as lying in the following groups:

(1) An *anterior or pectoral group*, lying along the medial wall of the axilla with the lateral thoracic artery, at the lower border of pectoralis minor. They receive from the upper half of the trunk anteriorly and from the *major part of the breast*.

(2) A *posterior or subscapular group*, lying along the medial wall of the axilla in the posterior part, i.e. along the subscapular artery. They receive from the upper half of the trunk posteriorly, and from the axillary tail of the breast.

(3) A *lateral group*, lying along the medial side of the axillary vein. They receive from the upper limb.

(4) A *central group*, lying in the fat of the axilla and receiving lymph from the above groups.

(5) An *apical group*, lying in the apex of the axilla, receives from all the groups named above. The apical group drains by the subclavian lymph trunk through the apex of the axilla into supraclavicular nodes lying in the

lower part of the posterior triangle of the neck. These drain into the thoracic duct or the right lymphatic trunk.

PART 3 BREAST

The adult **female breast** or mammary gland lies in the subcutaneous tissue (superficial fascia) of the anterior thoracic wall. Despite individual variations in size, the extent of the *base* of the breast is fairly constant: from near the midline to near the midaxillary line, and from the second to the sixth ribs. It overlies pectoralis major, overlapping on to serratus anterior and to a small part of the rectus sheath and external oblique muscle. A small part of the upper outer quadrant may extend laterally to form the axillary tail (but not always present); it lies in the medial wall of the axilla and may be a discrete mass poorly connected with the duct

system. Usually it lies in the subcutaneous fat, which is condensed around it; rarely it may penetrate the deep fascia of the axillary floor and so lie adjacent to some axillary lymph nodes.

Some 15–20 *lactiferous ducts* converge in a radial direction to open on the *nipple*, the projection just below the centre of the breast which is surrounded by an area of pigmented skin, the *areola*. Some large sebaceous glands under the areola (*areolar glands*) may form small elevations (tubercles of Montgomery).

Behind the breast the superficial fascia (the upward continuation of the membranous layer of superficial abdominal fascia of Scarpa) is condensed to form a posterior capsule. Strands of fibrous tissue (forming the *suspensory ligaments* of Cooper) connect the dermis of the overlying skin to this fascia, and help to maintain the protuberance of the young breast; with the atrophy of age they allow the breast to become pendulous, and when contracted by carcinoma they cause pitting of the skin. Between the capsule and the fascia over pectoralis major is the *retromammary space*, traversed by lymph vessels and some blood vessels but relatively avascular. It is the space into which breast prostheses are usually inserted, and access to it is most commonly through an incision above and parallel to the submammary skin crease.

The *male breast* resembles the rudimentary female breast; the nipple is small with an areola and lies over the fourth intercostal space; mammary tissue does not extend beyond the areola.

Blood supply

This is derived mainly from the *lateral thoracic artery* by branches that curl around the border of pectoralis major and by other branches that pierce the muscle. The *internal thoracic artery* also sends branches through the intercostal spaces beside the sternum; those of the second and third spaces are the largest. Similar but small perforating branches arise from the intercostal arteries; as mentioned above, the space superficial to pectoralis major is relatively bloodless. Pectoral branches of the *thoracoacromial artery* supply the upper part of the breast. The various supplying vessels form an anastomosing network. Venous drainage is mainly by deep veins that run with the main arteries to internal thoracic and axillary veins. Some drainage to posterior intercostal veins provides an important link to vertebral veins (p. 543) and hence a pathway for metastatic spread to bone. Superficial veins may anastomose across the midline (though not all authorities subscribe to this suggestion).

Lymph drainage

This is of the utmost importance in connexion with the spread of malignant disease.

From numerous lymphatic capillaries in the breast substance and the overlying skin, lymph from the lateral part of the breast (upper and lower outer quadrants) drains to axillary and infraclavicular nodes (p. 70), while from the medial part (upper and lower inner quadrants) it drains through the intercostal spaces into internal thoracic (parasternal) nodes. This is what might be expected — the lateral part draining laterally and the medial part medially, but it is important to note that there can be lymph flow between the lateral and medial parts of the breast and vice versa, possibly aided by the pressure of clothing or the examiner's hand. Some nodes may be embedded within breast tissue in the upper outer quadrant, and some may lie between pectoralis major and minor. There are no valves in the intramammary channels. Most lymph drains to the axilla; some of the internal thoracic nodes, which are mainly in the first three interspaces within 3 cm of the sternal margin, are very small and may easily be missed. Superficial lymphatics may cross the midline (like veins, see above, but again some authorities deny this). The old concept that the skin and subareolar regions drained separately from the breast parenchyma is no longer tenable. But other pathways become possible, especially when the more usual channels have become obstructed, and lymph may then pass to the opposite breast, to cervical nodes, to the peritoneal cavity and liver through the diaphragm or through the rectus sheath, or even to inguinal nodes via the anterior abdominal wall.

Nerve supply

The overlying skin is supplied by the cutaneous branches of intercostal nerves T4 to T6. Sympathetic fibres supply the blood vessels and glands, but the control of lactation is hormonal.

Structure

The resting (non-lactating) breast consists mostly of fibrous and fatty tissue; variations in size are due to variations in fat content, not glandular tissue which is very sparse and is little more than a system of blind-ending ducts. The *areolar glands* are typical sebaceous glands. Fibrous septa (the largest of which are the suspensory ligaments, see above) divide the breast into irregular lobules from which the *lactiferous ducts* converge to open on the summit of the nipple, each

duct having a dilated *sinus* just below the nipple. Prior to lactation alveoli bud off from the smaller ducts into the surrounding tissue and the organ usually enlarges significantly, and more so in preparation for lactation. After lactation and after the menopause there is resorption of glandular and other tissues.

Development

The breast is a modified apocrine sweat gland (p. 2) and begins to develop as early as the fourth week as a downgrowth from a thickened *mammary ridge* (milk line) of ectoderm along a line from the axilla to the inguinal region. Supernumerary nipples or even glands proper may form at lower levels on this line.

Mastectomy

The extensive removal of the breast and adjacent tissues for carcinoma so common in earlier decades has now given place in many cases to local excision supplemented by radiotherapy and chemotherapy. If simple mastectomy is required, the breast is stripped off the pectoralis fascia and adjacent muscles, together with axillary fat and lymph nodes. For more radical procedures, one or both pectoral muscles can be removed as well. In axillary dissections, damage to the long thoracic and thoracodorsal nerves (as well as to the main branches of the brachial plexus) must be avoided, but the intercostobrachial nerve can be cut when clearing fat and lymph nodes. If both pectoral muscles are being removed the pectoral nerves can also be cut, but if pectoralis major remains the lateral pectoral nerve must be preserved so that at least part of the muscle retains a nerve supply.

PART 4

SHOULDER REGION

A group of six muscles — muscles of the shoulder — converge from the scapula on to the humerus and surround the shoulder joint: deltoid, supraspinatus, infraspinatus, teres minor, teres major and subscapularis. Three of them (supraspinatus, infraspinatus and teres minor) extend from the posterior surface of the blade of the scapula to be inserted into the three impressions on the greater tuberosity of the humerus. Subscapularis passes from the thoracic surface of the scapula to the lesser tuberosity, and teres major from the inferior angle of the scapula to the shaft of the

humerus. All these muscles lie hidden, for the most part, under deltoid and trapezius. Subscapularis and teres major have already been described (p. 63).

Supraspinatus

The muscle fills snugly the whole of the supraspinous fossa of the scapula (Fig. 2.16). It arises from the medial three-fourths of the fossa and from the upper surface of the scapular spine. It is bipennate, an arrangement that gives this bulky muscle great force of pull. A bursa separates it from the lateral fourth of the fossa. The tendon develops deep to the muscle as it crosses the superior part of the capsule of the shoulder joint; the two become blended together, to the great advantage of the capsule. The tendon passes on to be inserted into the smooth facet on the upper part of the greater tuberosity (Fig. 2.60).

Nerve supply. By the suprascapular nerve (C5, 6), from the upper trunk of the brachial plexus, passing beneath the superficial transverse scapular ligament which bridges the suprascapular notch, and supplying the muscle by two branches.

Action. The muscle is of primary importance in bracing the head of the humerus to the glenoid cavity, to give stability during the action of other muscles, especially the deltoid, which it assists in abduction at the shoulder joint (p. 77).

Test. The arm is abducted against resistance and the muscle palpated (deep to trapezius) above the scapular spine.

Infraspinatus

The muscle arises from beneath a dense fascia (see below) from the medial three-fourths of the infraspinous fossa (Fig. 2.16). Fibrous intramuscular septa give added attachment to the multipennate fibres, which converge to slide freely over the bare area of the scapula at its lateral angle. A bursa lies between the two and it sometimes communicates with the shoulder joint. Here tendon replaces the muscle fibres, and is blended with the capsule of the shoulder joint, greatly increasing its strength. The tendon is inserted into the smooth area on the central facet of the greater tuberosity of the humerus (Fig. 2.60), between supraspinatus above and teres minor below.

Nerve supply. By the suprascapular nerve (C5, 6) from the upper trunk of the brachial plexus. After giving branches to supraspinatus (see above), the nerve passes around the lateral border of the scapular spine and enters the infraspinous fossa to give two branches to the muscle.

Action. Apart from acting to brace the head of the humerus against the glenoid cavity, giving stability to the joint in movements of the peripheral parts of the limb, the muscle is also a powerful lateral rotator of the humerus.

Test. With the elbow flexed and held into the side, the forearm is moved outwards against resistance. The muscle is palpated (deep to trapezius) below the scapular spine and is usually visible.

Teres minor

The muscle is completely hidden beneath the deltoid. It arises from an elongated oval area at the axillary border of the scapula. It passes upwards and laterally, edge to edge with the lower border of infraspinatus (Fig. 2.16), to the lowest facet on the greater tuberosity of the humerus and to a thumb's breadth of bone below this. It passes *behind* the origin of the long head of triceps. At the lower border it lies edge to edge with teres major at its origin, but the latter muscle leaves it by passing forward *in front of* the long head of triceps (Fig. 2.16).

Nerve supply. By a branch from the posterior branch of the axillary nerve (C5, 6), from the posterior cord of the brachial plexus.

Action. It assists the other small muscles around the head of the humerus in steadying the shoulder joint in movements of peripheral parts of the limb. More specifically, it can act as a lateral rotator and weak adductor of the humerus. With the teres major it holds down the head of the humerus against the upward pull of the deltoid during abduction of the shoulder (Fig. 2.20).

Infraspinatus fascia

The infraspinatus and teres minor muscles lie together beneath a very strong membrane which is firmly attached to bone at the margins of these muscles. It is attached above to the lower border of the scapular spine beneath the deltoid muscle, and medially along the vertebral border of the scapula. It is attached to the axillary border of the scapula along the sinuous ridge that can be seen running down from the infraglenoid tubercle. Examine a scapula and note that this ridge runs back to the dorsal surface of the bone above the origin of teres major. The latter muscle does not lie beneath the fascia (Fig. 2.5).

The importance of the infraspinatus fascia is not confined to its value as a landmark in surgical exposures of this region, but lies in the fact that in fracture of the blade of the scapula the resulting haematoma is confined beneath the fascia. A large rounded swelling

that is *limited to the margins of the bone* is diagnostic of fracture.

Deltoid

This powerful muscle arises from a long strip of bone and converges triangularly to its insertion on the deltoid tuberosity. It covers the shoulder joint like a cape (Fig. 2.1) and its convex shape is due to the underlying upper end of the humerus. The anterior and posterior fibres are long, and in parallel bundles. The intermediate, or acromial fibres are multipennate.

The muscle arises from the anterior border and upper surface of the flattened lateral one-third of the clavicle, from the whole of the lateral border of the acromion and from the inferior lip of the crest of the scapular spine as far medially as the 'deltoid' tubercle. On the lateral border of the acromion four ridges may be seen; from them four fibrous septa pass down into the muscle. The deltoid tuberosity on the humerus is U-shaped, with a central vertical ridge. From the ridge and limbs of the U three fibrous septa pass upwards between the four septa from the acromion. The spaces between the septa are filled with a fleshy mass of oblique muscle fibres which are attached to contiguous septa. The multipennate centre of the deltoid so formed has a diminished range of contraction, but a correspondingly increased force of pull. The anterior and posterior fibres, arising from the clavicle and the scapular spine, are not multipennate. They converge on the limbs of the U-shaped deltoid tuberosity of the humerus. Their range of movement is greater but the force of their pull is less than that of the multipennate central portion of the muscle.

Nerve supply. By the axillary nerve (C5, 6) from the posterior cord of the brachial plexus. The nerve runs transversely round the back and lateral side of the surgical neck of the humerus giving off numerous branches that enter the muscle in *radial* directions; splitting the muscle vertically does not damage the nerve supply. The *surface marking* of the nerve is along a transverse line about 5 cm below the tip of the acromion.

Action. Working with supraspinatus, deltoid abducts the arm (p. 77). It is the main abductor, most of this work being done by the multipennate acromial fibres. The anterior and posterior fibres act like guy ropes to steady the arm in the abducted position. The anterior fibres acting alone assist pectoralis major in flexing and medially rotating the arm; the posterior fibres assist latissimus dorsi in extending the arm and act as a lateral rotator (acting in adduction to counteract the medial rotation of pectoralis major and latissimus).

In tetraplegia the posterior third of deltoid can be transferred to triceps to produce elbow extension.

Test. The arm is abducted against resistance and the muscle is seen and felt.

Intramuscular injection. The site for intramuscular injection into deltoid is on the lateral side of the bulge of the shoulder, no more than 4 cm below the lower border of the acromion; the axillary nerve curls forwards round the back of the humerus 5–6 cm below the acromion.

Scapular anastomosis

The *transverse cervical artery* from the subclavian, via the thyrocervical trunk or sometimes directly, has a deep or descending branch (often called the *dorsal scapular artery* — see p. 444) which accompanies the dorsal scapular nerve. It runs down the vertebral border of the scapula to its inferior angle (Fig. 2.17). The *suprascapular artery* from the subclavian, usually the first part (thyrocervical trunk in common with the transverse cervical) but occasionally the third part, crosses over the superficial transverse scapular ligament, passes through the supraspinous fossa, turns around the lateral

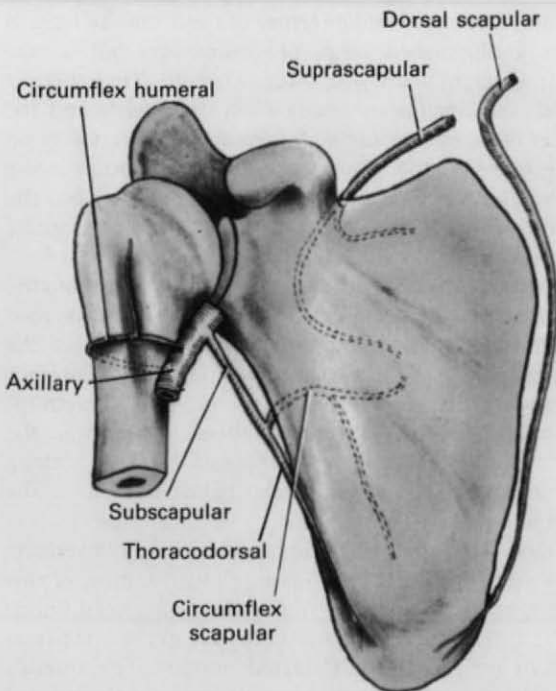


Fig. 2.17 Scapular anastomosis. The dorsal scapular and suprascapular arteries arise from the third and first parts of the subclavian, and the subscapular from the third part of the axillary artery. They and the circumflex scapular anastomose on both surfaces of the scapula.

border of the spine of the scapula and supplies the infraspinous fossa as far as the inferior angle. The *subscapular artery*, branching from the third part of the axillary, supplies the subscapularis muscle in the subscapular fossa as far as the inferior angle. Its *circumflex scapular branch* enters the infraspinous fossa on the dorsal surface of the bone. All the vessels anastomose, thus connecting the first part of the subclavian with the third part of the axillary artery. The companion veins form corresponding anastomoses.

SHOULDER JOINT

In all tetrapods there is a scapula which is dorsal and a coracoid which is ventral. The humerus always articulates at the junction of the two elements. In the human shoulder, scapula and coracoid articulate with each other across the joint line (Fig. 2.9). The presence of an epiphyseal cartilage across a joint line is beneficial in that it facilitates adjustment of the joint surfaces during growth of the bone ends (as at the shoulder, elbow and hip).

The **shoulder joint** is a synovial joint of the ball and socket variety. There is a 4 to 1 disproportion between the large round head of the humerus and the small shallow glenoid cavity. The **glenoid labrum**, a ring of fibrocartilage attached to the margins of the glenoid cavity, deepens slightly but effectively the depression of the glenoid 'fossa' (Fig. 2.9).

The **capsule** of the joint is attached to the scapula beyond the supraglenoid tubercle and the margins of the labrum. It is attached to the humerus around the articular margins of the head (i.e. the anatomical neck) except inferiorly, where its attachment is to the surgical neck of the humerus a finger's breadth below the articular margin (Fig. 2.18A). At the upper end of the intertubercular groove the capsule bridges the gap between the greater and lesser tuberosities, being here named the **transverse humeral ligament**. A gap in the anterior part of the capsule allows communication between the synovial membrane and the subscapularis bursa (Figs 2.11 and 2.18). A similar gap is sometimes present posteriorly, allowing communication with the infraspinatus bursa. The fibres of the capsule all run horizontally between scapula and humerus. The capsule is thick and strong but it is very lax, a necessity in a joint so mobile as this. Near the humerus the capsule is greatly thickened by fusion of the tendons of the short scapular muscles. The long tendon of biceps is intracapsular.

The **synovial membrane** is attached around the glenoid labrum and lines the capsule. It is attached to the articular margin of the head of the humerus and

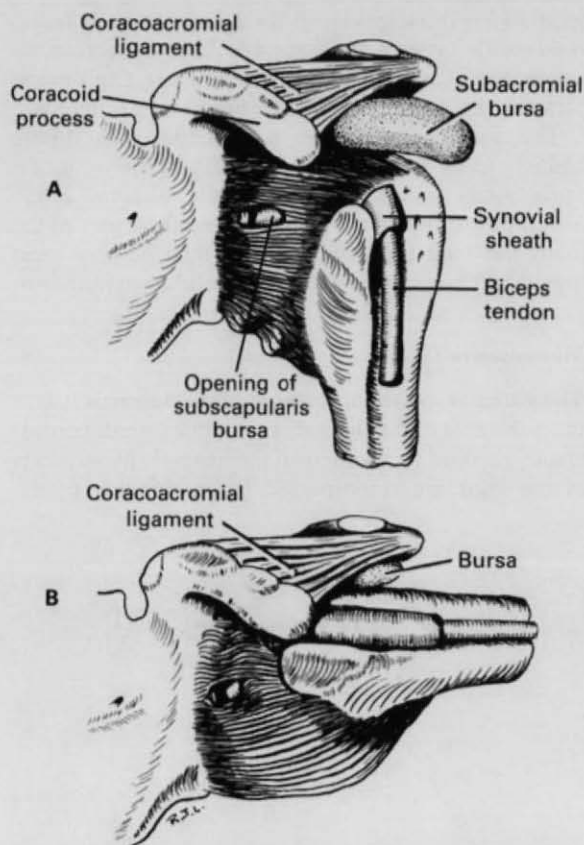


Fig. 2.18 Left subacromial bursa. In **A** with the arm by the side, the bursa is only half under cover of the acromion, but in **B** with the arm abducted the bursa is withdrawn beneath the acromion.

covers the bare area of the surgical neck that lies within the capsule at the upper end of the shaft. It 'herniates' through the hole in the front of the capsule to communicate with the subscapularis bursa and sometimes it communicates with the infraspinatus bursa. It invests the long head of biceps in a tubular sleeve that is reflected back along the tendon to the transverse ligament and adjoining floor of the intertubercular groove. The synovial sleeve glides to and fro with the long tendon of biceps during abduction-adduction of the shoulder, as shown in Figure 2.18A and B.

The **glenohumeral ligaments** are scarcely worthy of mention, being slight thickenings above and below the opening into the subscapularis bursa in the anterior part of the capsule. They are visible only from within the joint cavity.

The **coracohumeral ligament** is quite strong. It runs from the under surface of the coracoid process

laterally across the capsule, to which it becomes attached at the margin of the greater tuberosity, and along the transverse ligament.

From the medial border of the acromion, in front of the acromioclavicular articulation, a strong flat triangular band, the **coracoacromial ligament**, fans out to the lateral border of the coracoid process (Fig. 2.18). It lies above the head of the humerus and serves to increase the surface upon which the head of the humerus may be supported. It is separated from the 'rotator cuff' by the subacromial bursa (Fig. 2.18).

The **subacromial (subdeltoid) bursa** is a large bursa which lies under the coracoacromial ligament, to which its upper layer is attached. Its lower layer is attached to the tendon of supraspinatus. It extends beyond the lateral border of the acromion with the arm at the side, but is rolled inwards under the acromion when the arm is abducted. Tenderness over the greater tuberosity of the humerus beneath the deltoid muscle which disappears when the arm is abducted indicates subacromial bursitis. Tearing the supraspinatus tendon brings the bursa into communication with the shoulder joint cavity, but in the normal shoulder the bursa never communicates with the joint.

Nerve supply. By branches from the axillary, musculocutaneous and suprascapular nerves (Hilton's law, p. 12).

Stability

The shoulder joint, thus far described, is seen to be a very unstable structure. The head of the humerus is much larger than the glenoid cavity (Fig. 2.19), and the joint capsule, though strong, is very lax. True it is that the concavity of the glenoid cavity, deepened by the labrum, is a significant stabilizing factor. But this is only because the short scapular muscles hold the head in close apposition. Fracture of the labrum results in dislocation. Stability is increased by the coracoacromial arch, the fusion of tendons of scapular muscles with the capsule of the joint, and the muscles attaching the humerus to the pectoral girdle.

Upward displacement of the head of the humerus is prevented by the overhanging coracoid and acromion processes and the coracoacromial ligament that bridges them. The whole constitutes the coracoacromial arch and, lubricated by the subacromial bursa, functions mechanically as an 'articular surface' of the shoulder joint. The arch is very strong. Upward thrust on the humerus will never fracture the arch; the clavicle or the humerus itself will fracture first.

The tendons of subscapularis, supraspinatus, infraspinatus and teres minor are not only attached very

near the joint but actually in part fuse with the lateral part of the capsule. This is an indispensable factor in adding stability to the joint. The fused mass of tendon and lateral part of capsule is known surgically as the '**rotator cuff**'. The rotator cuff prevents the lax capsule and its lining synovial membrane from being nipped. There is no cuff inferiorly, and here the capsule is attached well below the articular margin to prevent its being nipped. Note that supraspinatus does not have any rotatory action on the humerus, although the other three muscles do.

The muscles attaching the humerus to the pectoral girdle all assist by their tonus in maintaining the stability of the joint. Especially active in this respect are the long heads of biceps and triceps.

The *long head of biceps*, arising from the supraglenoid tubercle, sinks in through the capsule of the embryonic

joint and is intracapsular in the mature joint. It leaves the capsule beneath the transverse ligament across the upper part of the intertubercular groove. The tendon acts as a strong support over the head of the humerus.

The *long head of triceps* is of importance during abduction of the joint for, in this position, it lies immediately beneath the head of the humerus at the lowest part of the joint. This is the weakest part of the joint; the long head of triceps is thus of very great importance in giving stability to the abducted humerus.

Movements

The articular surface of the head of the humerus is four times the area of the glenoid cavity; thus there is considerable freedom for a variety of movements. Movements at the joint are accompanied by movements of the

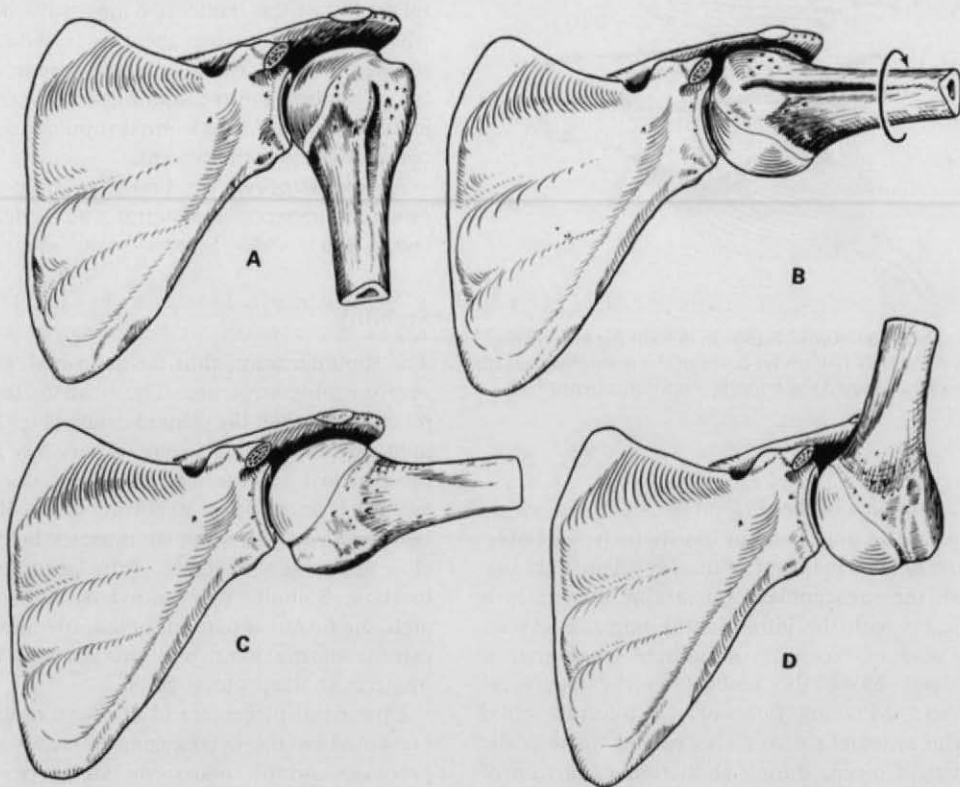


Fig. 2.19 Bony factors in abduction at the shoulder joint. (The coracoid process has been removed.) **A** With the arm by the side. **B** Abduction to 90° . Compare with **A** and note that all the available articular surface of the head of the humerus has been used up. **C** With lateral rotation of the humerus from position **B**. More of the articular surface has been made available from below to above the glenoid cavity, but such free rotation is limited in the living by the rotator cuff muscles. **D** Full abduction from the rotated position in **C**, but note that in the living abduction is limited to about 120° ; scapular rotation accounts for the remaining 60° . The movements in **B** to **D** take place in the plane of the paper (the coronal plane of the body), but the final position in **D** can be reached directly by movement at right angles to the paper (flexion in the sagittal plane carried up to full abduction).

scapula on the thoracic wall and by consequential movements of the clavicle.

These various movements of the shoulder joint itself, however, can be understood only if each is analysed into its constituent parts. These basic movements are only three: (1) flexion and extension, (2) adduction and abduction, and (3) rotation. Note that *circumduction* is merely a rhythmical combination in orderly sequence of flexion, abduction, extension and adduction (or the reverse), and for purposes of analysis it is not an elementary movement.

It is of clinical value to appreciate the fact that the medial epicondyle of the humerus faces in the same direction as the articular surface of the head. Note that this is not exactly medial, but rather medial and somewhat backwards. The glenoid cavity does not face exactly laterally, but peeps forward a little around the convexity of the thoracic wall, and the articular surface on the head of the humerus looks back towards it. The purist may claim that flexion and extension should be described as movements in the plane of the joint cavity, which is oblique to the sagittal plane, and that abduction and adduction should be defined as movements in a plane at right angles to this, which is oblique to the coronal plane. But for purposes of analysis of these movements the difference is negligible.

Examine the humerus and scapula. Any of the basic movements under review is limited in its range (apart from tension in ligaments or muscles) by the available articular surface on the head of the humerus. When glenoid cavity and humeral head lie margin to margin, further movement is impossible without dislocation of the joint.

With the arm at the side (Fig. 2.19A) *adduction* is very limited in range, not only by compression of soft parts but also because very little surface of the humerus is available. *Abduction* from this position is limited to about 90°. Fixation here is not due to bony interlocking between greater tuberosity and acromion, but to the fact that *no further articular surface is available on the humerus* (Fig. 2.19B). Further abduction in this position can only result in dislocation of the head of the humerus. The available free surface of humeral head lies below the joint. If this free surface is now put above the joint by lateral rotation of the humerus (Fig. 2.19C), further abduction is made possible (Fig. 2.19D). Note that this final position of full abduction in lateral rotation (Fig. 2.19D), reached through the coronal plane, can be achieved in the sagittal plane by a simple pendulum movement of the humerus, carrying the normal forward swing of flexion straight up into full abduction. *Flexion* is free and direct from A to

D (Fig. 2.19) with no rotation of the humerus. *Abduction* from A to D is possible only with lateral rotation of the humerus. In each case the final position of the humerus is the same. In 180° of abduction about 120° takes place at the shoulder joint and 60° is provided by scapular rotation, i.e. over the whole range the ratio of shoulder joint to scapular movement is 2 to 1. But for the first 30° or so there is negligible scapular movement which only becomes noticeable beyond this.

Rotation of the humerus can be performed, about its long axis, in any position. It is limited by the extent of the articular surface on the humerus, and by simultaneous tension in the appropriate part of the capsule. About 90° of lateral rotation is normal and the same amount for medial rotation, although when the arm is hanging by the side with the elbow flexed medial rotation appears to be limited to 70° by contact with the body wall; if the humerus is abducted to a right angle the full 90° can be obtained.

Abduction in the coronal plane is produced by deltoid assisted by supraspinatus. It is usually considered that supraspinatus initiates abduction, with the acromial fibres of deltoid adding force after the movement has begun; both muscles then act together. The pull of supraspinatus appears to cause the head of the humerus to move *down* slightly as the greater tuberosity is pulled upwards and medially (Fig. 2.20A). Supraspinatus is not usually considered capable by itself of producing the full range of glenohumeral movement, but with deltoid completely paralysed rare cases have been recorded when it can. The downward pull on the head of the humerus by subscapularis, teres major and minor, and infraspinatus acts as a stabilizing couple against the upward pull of the deltoid (Fig. 2.20B).

Adduction is produced by the short scapular muscles (except supraspinatus) when deltoid relaxes, and the movement is much strengthened by contraction of the great muscles of the axillary walls, pectoralis major and latissimus dorsi.

Flexion is produced by the clavicular head of pectoralis major and the anterior fibres of deltoid, assisted by coracobrachialis and biceps. From full extension the sternocostal head of pectoralis major is also involved. **Extension** is produced by latissimus dorsi, the posterior fibres of deltoid and the long head of triceps.

Rotation is produced chiefly by the short scapular muscles: infraspinatus and teres minor for lateral rotation, subscapularis and teres major for medial rotation.

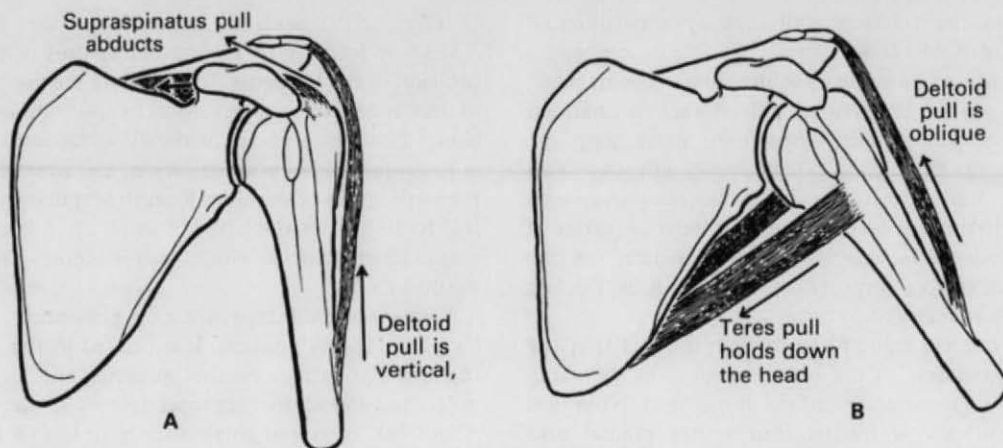


Fig. 2.20 Abduction at the shoulder joint, which is the result of the combined activities of **A**, supraspinatus pulling on the top of the greater tuberosity, and **B**, deltoid pulling on the middle of the shaft. The teres muscles help to prevent upward movement of the head of the humerus as deltoid and supraspinatus abduct.

As a test for lateral rotation, put the hand behind the head, comparing the two limbs. For medial rotation, put the hand on the back between the scapulae.

Surgical approach

The joint can be exposed from the front or back. From the front the deltopectoral groove is opened up, ligating tributaries of the cephalic vein, and the tip of the coracoid process is detached and turned medially with coracobrachialis and the short head of biceps still attached, taking care not to damage the musculocutaneous nerve entering coracobrachialis. Subscapularis is stretched by laterally rotating the humerus and then divided to expose the joint capsule. The anterior circumflex humeral vessels are a guide to the lateral (lower) border of the muscle.

From the back deltoid is detached from the spine of the scapula and acromion and reflected laterally to allow infraspinatus and teres minor to be cut to expose the capsule. The axillary nerve and posterior circumflex humeral vessels must not be damaged when reflecting deltoid.

Injection or aspiration of the joint can be carried out from the side below the acromion, from the back below the junction of the acromion with the spine and in the direction of the coracoid process, or from the front with the needle passing through the deltopectoral groove and then below and medial to the tip of the coracoid process, through the coracobrachialis-biceps origin and subscapularis.

PART 5

ANTERIOR COMPARTMENT OF THE ARM

Part of the anterior or flexor compartment in both the arm and the thigh is occupied by the adductor musculature. In the thigh this is differentiated into adductors longus, brevis, and that part of magnus innervated from the obturator nerve (p. 160). In the arm the adductor musculature is represented by the rather insignificant coracobrachialis muscle; the function of adduction has been taken over by the well-developed muscles in the anterior and posterior axillary walls. The nerve of the flexor compartment is the musculocutaneous.

Coracobrachialis

Functionally unimportant, the muscle nevertheless shows several interesting morphological and anatomical characteristics. It is the counterpart in the arm of the adductors (longus, brevis, magnus) of the thigh. It arises from the apex of the coracoid process, where it is fused with the medial side of the short head of biceps. The tendon is continued into a muscular belly of varying development which is inserted into the medial border of the humerus. The lower extent of the insertion is marked by the nutrient foramen of the humerus, for the nutrient branch of the brachial artery runs along

the lower border of the muscle. The upward extent of the insertion cannot be seen on most bones, the muscle usually leaving no impression.

The musculocutaneous nerve passes *through* the muscle. This is explained in terms of comparative anatomy. In some animals the muscle has three heads; in man two have fused, trapping the nerve between them, and the third part has become suppressed. The occasional supratrochlear spur (on the anteromedial aspect of the lower humerus) may be continuous with a ligament (of Struthers, Fig. 2.21) which passes to the medial epicondyle and represents the remains of the third head. The median nerve or brachial artery or both may run beneath it and be subject to compression.

Nerve supply. By the musculocutaneous nerve (C5, 6). The main trunk of the nerve passes through the muscle, first giving off its branch of supply (Fig. 2.12).

Action. Compared to the morphological interest of this muscle its action is negligible. It is a weak flexor and adductor of the shoulder joint, the main adductors of which are pectoralis major and latissimus dorsi.

Biceps

The **long head** of this muscle arises from the supraglenoid tubercle and adjoining part of the glenoid labrum of the scapula (Fig. 2.9). The rounded tendon passes through the synovial cavity of the shoulder joint, surrounded by synovial membrane, and emerges beneath the transverse ligament at the upper end of the intertubercular groove. The membrane pouts out below the ligament to an extent which varies with the position

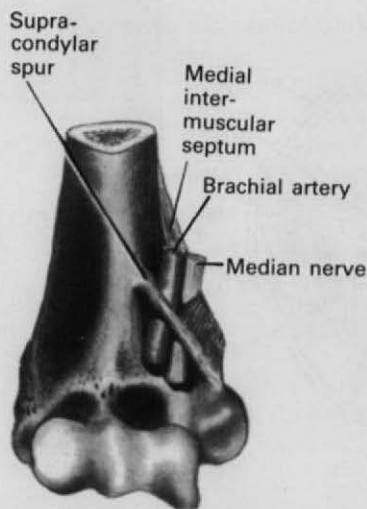


Fig. 2.21 Right supratrochlear spur and the ligament of Struthers overlying the brachial artery and median nerve.

of the arm, being greatest in full abduction (Fig. 2.18). The range of mobility of the tendon under the transverse ligament between full adduction and abduction of the shoulder joint is 6 cm. The long tendon develops outside the capsule, then sinks through it, then hangs on a mesotendon which subsequently breaks down. This embryological progression may become arrested at any stage.

The **short head** arises from the apex of the coracoid process to the lateral side of coracobrachialis. The tendinous origin of each head expands into a fleshy belly; the two bellies lie side by side, loosely connected by areolar tissue, but do not merge until just above the elbow joint, below the main convexity of the muscle belly. The tendon at the lower end, flat from side to side, lies across the elbow joint and converges into a flattened cord which rotates (anterior surface turning laterally) as it passes through the cubital fossa to its insertion into the posterior border of the tuberosity of the radius (Fig. 2.27). A bursa separates the tendon from the anterior part of the tuberosity. From the medial border of the tendon, at the level of the elbow joint, the **bicipital aponeurosis** (Fig. 2.30) is inserted by way of the deep fascia of the forearm into the subcutaneous border of the upper end of the ulna. This aponeurosis has a sharp concave upper margin which can be felt tensed when the supinated forearm is flexed to a right angle. The main tendon, sliding in and out of the cubital fossa during pronation and supination, has a total range of movement of 6 cm.

Nerve supply. By the musculocutaneous nerve (C5, 6) with one branch to each belly.

Action. Biceps acts on three joints: shoulder, elbow and proximal radioulnar. If the elbow is extended the muscle is a simple flexor thereof, but in any position of the elbow short of full extension the biceps is a powerful supinator of the forearm, triceps contracting to prevent flexion at the elbow joint. In full supination the bicipital aponeurosis is pulled taut and biceps then pulls on *both* bones of the forearm to flex the elbow. Unopposed by triceps the biceps, while supinating the forearm, flexes the elbow and shoulder joints. It 'puts in the corkscrew then pulls out the cork'. The long head helps to stabilize the shoulder joint because its tendon of origin runs over the top of the head of the humerus. If deltoid is paralysed, biceps may help in abduction.

Test. With the forearm supinated the elbow is flexed against resistance. The muscle is easy to inspect and palpate.

Brachialis

The muscle arises from the front of the lower two-

thirds of the humerus and the medial intermuscular septum. Its upper fibres *clasp the deltoid insertion*; some fibres arise from the lower part of the radial groove. The broad muscle flattens to cover the anterior part of the elbow joint (with some fibres attaching to the front of the capsule) and is inserted by mixed tendon and muscle fibres into the coronoid process and tuberosity of the ulna (Fig. 2.31).

Nerve supply. By the musculocutaneous nerve (C5, 6). Some of the lateral part of the muscle is innervated by a branch of the radial nerve, an indication that it was developed in the extensor compartment of the fetal limb (p. 23).

Action. Principally a flexor of the elbow joint, the muscle, together with biceps, is used just as frequently as an *extensor* of the elbow, 'paying out rope' against gravity. 'It picks up the drink and puts down the empty glass.' Some fibres pull the capsule of the elbow joint upwards and prevent entrapment of the capsule between the humerus and ulna.

Medial intermuscular septum

This septum extends along the medial supracondylar line behind the coracobrachialis insertion and fades out above, between that muscle and the long head of triceps. It gives origin to the most medial fibres of brachialis and the medial head of triceps, and is pierced by the ulnar nerve and ulnar collateral artery.

Lateral intermuscular septum

This extends along the lateral supracondylar line and fades out behind the insertion of deltoid. Both brachioradialis and extensor carpi radialis longus extend out from the humerus to gain attachment to the septum in front, and posteriorly the *medial* head of triceps arises from it. It is pierced by the radial nerve and profunda brachii artery (anterior descending branch).

NERVES AND VESSELS OF THE ARM

The neurovascular bundle from the axilla passes into the flexor compartment of the arm. Some branches (circumflex vessels and axillary nerve) are given to the extensor compartment in the axilla, which they leave through the quadrangular space. In the upper part of the arm the radial nerve and profunda brachii artery leave to enter the extensor compartment through a triangular gap between the long head of triceps, the humerus and the lower margin of teres major. The remainder of the neurovascular structures pass through the flexor compartment (Fig. 2.22).

Brachial artery

This is the continuation of the axillary artery, which vessel has the axillary vein on its medial side. In the arm the vein is seen to be formed from venae comitantes to the brachial artery, strongly reinforced above by the basilic vein, which perforates the deep fascia at a point

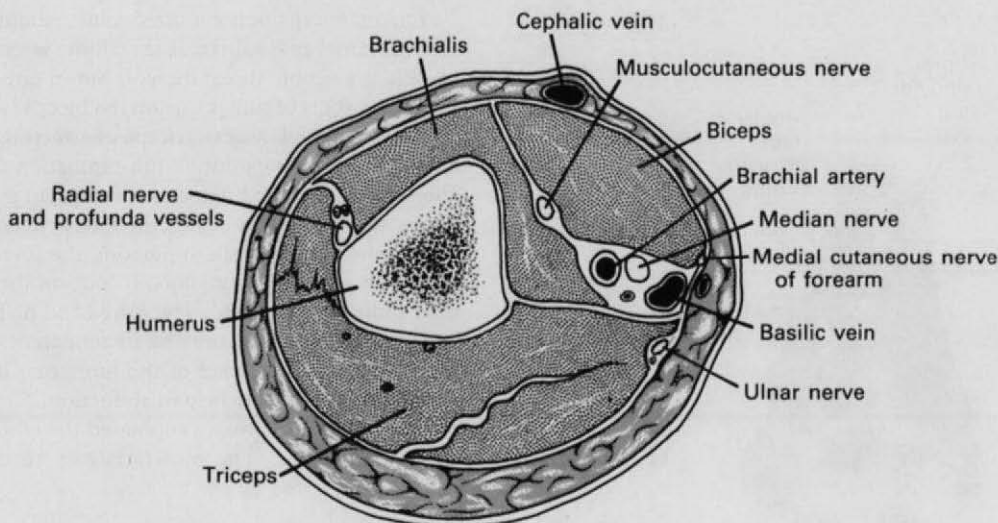


Fig. 2.22 Cross-section of the middle of the right upper arm, looking towards the shoulder. The brachial artery and the median, ulnar and musculocutaneous nerves are on the medial side, with the radial nerve lateral to the humerus.

opposite the deltoid insertion. The brachial artery has the median nerve lateral to it above (Fig. 2.12), but the nerve crosses very obliquely in front of the artery and lies on its medial side below. The ulnar nerve, posterior to the artery above, leaves it in the lower part of the arm and slopes backwards through the medial intermuscular septum. The vessel is superficial throughout its course in the arm, lying immediately deep to the deep fascia. It passes into the cubital fossa before dividing into the radial and ulnar arteries (p. 92), but occasionally the division is in the proximal part of the arm, giving rise to a 'superficial radial artery' which may be mistaken for a superficial vein.

To *palpate* the artery in the upper arm, the finger pressure must be directed *laterally*, not backwards, since the vessel here lies medial to the humerus (Fig. 2.15). The *surface marking* for the vessel is along a line from the medial bicipital groove behind coracobrachialis to the middle of the cubital fossa at a point level with the neck of the radius.

Surgical approach. The artery can be exposed at the medial border of biceps, in the groove between biceps and triceps. The deep fascia is incised and the groove opened up to display the neurovascular bundle embedded in connective tissue that is the downward continuation of the axillary sheath.

Branches. Apart from the terminal radial and ulnar arteries (p. 92), the largest branch is the *profunda brachii artery*. It leaves through the lower triangular space to run in the radial groove with the radial nerve. It supplies triceps and ends as anterior and posterior anastomotic branches which join the cubital anastomosis (p. 93).

Other branches are the *superior ulnar collateral* which accompanies the ulnar nerve (p. 82), and the *inferior ulnar collateral* which divides into anterior and posterior branches; all take part in the cubital anastomosis (p. 93). There are also muscular branches to flexor muscles, and a nutrient artery to the humerus which enters the bone near the coracobrachialis attachment.

Veins of the arm

Venae comitantes accompany the brachial artery and all its branches. In addition, the **basilic** and **cephalic veins** course upwards through the subcutaneous tissue (Fig. 2.23). The former perforates the deep fascia in the middle of the arm, the latter lies in the groove between deltoid and pectoralis major and ends by piercing the clavipectoral fascia to enter the axillary vein.

Median nerve

The nerve (Fig. 2.12) is formed at the lower border of

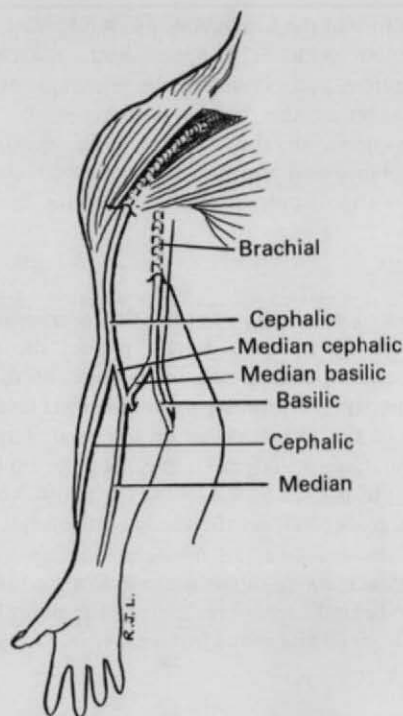


Fig. 2.23 Superficial veins of the right upper limb. The median forearm vein joins the cephalic and basilic veins which have begun on the dorsum of the hand; blood from the palm drains to the dorsum.

the axilla by the union of its medial and lateral roots, from the corresponding cords of the brachial plexus. The axillary artery is clasped between the two roots, the medial root crossing in front of the vessel. The commencement of the nerve is thus lateral to the artery. Passing distally through the arm the nerve lies in front of the brachial artery and at the elbow is found on its medial side. The nerve has no muscular branches in the arm (unless the nerve to pronator teres has an unusually high origin, Fig. 2.30), but it gives sympathetic filaments to the brachial artery and a twig to the elbow joint.

The *surface marking* of the nerve is along a line from the groove behind coracobrachialis to the cubital fossa medial to the (palpable) brachial artery.

Musculocutaneous nerve

Giving a twig to the shoulder joint and a branch to coracobrachialis (Fig. 2.12) the nerve proceeds between the two conjoined parts of coracobrachialis (p. 78), and comes to lie between biceps and brachialis, accompanied by many branches of the brachial artery

and tributaries of the brachial veins. While lying in this intermuscular plane it supplies both muscles. Its remaining fibres, purely cutaneous now, appear at the lateral margin of the biceps tendon as the lateral cutaneous nerve of the forearm (Fig. 2.30). The musculocutaneous is the nerve of the flexor compartment of the arm, supplying all three muscles therein.

Ulnar nerve

Lying posterior to the vessels this nerve inclines backwards away from them and pierces the medial intermuscular septum in the lower third of the arm, accompanied by the superior ulnar collateral artery and a branch of the radial nerve to the medial head of triceps (the 'ulnar collateral' nerve). It gives no branch in the arm; its branch to the elbow joint comes off as it lies in the groove behind the medial epicondyle of the humerus.

The *surface marking* of the nerve is along a line from the groove behind coracobrachialis to the point behind the medial epicondyle of the humerus where it is readily palpable.

Medial cutaneous nerve of the arm

Lying anterior to the vessels this small nerve pierces the deep fascia in the upper part of the arm and supplies the skin on the front and medial side of the upper part of the arm (Fig. 2.57).

Medial cutaneous nerve of the forearm

Commencing on the medial side of the vessels this large nerve passes anterior to them and pierces the deep fascia on the medial side of the arm together with the basilic vein. It supplies skin over the lower part of the arm; the main part of the nerve passes into the medial side of the forearm (Fig. 2.57).

Intercostobrachial nerve

The skin of the axilla is supplied by the lateral cutaneous branch of the second intercostal nerve. This nerve, known as the intercostobrachial, extends for a variable distance into the skin on the medial side of the upper arm (Fig. 2.57). Not infrequently the lateral cutaneous branch of the third intercostal nerve also extends out to supply the skin of the axilla.

Lymph nodes

Two groups of lymph nodes (not part of the axillary

group, p. 69) are found in the arm. The **infraclavicular group** lie along the cephalic vein in the upper part of the deltopectoral groove and drain through the clavipectoral fascia into the apical axillary nodes. The **supratrochlear group** lie in the subcutaneous fat just above the medial epicondyle. They drain the superficial tissues of the ulnar side of the forearm and hand, the afferent lymphatics running with the median basilic vein and its tributaries. Their efferent vessels pass to the lateral group of axillary nodes.

PART 6

POSTERIOR COMPARTMENT OF THE ARM

The extensor compartment is occupied by the triceps muscle, through which run the radial nerve and profunda artery. The ulnar nerve runs through the lower part of this compartment.

Triceps

The three heads of this muscle are named long, lateral and medial—unfortunate names, since the medial would be far better called the deep head, and the long head is, in fact, medial. The **long head** arises from the infraglenoid tubercle at the upper end of the axillary border of the scapula. The **lateral head** has a linear origin (Fig. 2.16) from the back of the humerus extending from the surgical neck to the top of the deltoid insertion. The long and lateral heads converge and fuse into a flattened tendon which lies superficially on the lower part of the muscle, and is inserted into the posterior part of the upper surface of the olecranon (Fig. 2.24). The **medial head** arises on the medial side of the radial groove of the humerus. Thus, in its upper part, it lies medial to the lateral head, with the radial nerve and profunda brachii vessels between them. Below the radial groove, however, the origin widens to include the whole posterior surface of the humerus and of *each* intermuscular septum. The fibres of the medial head that arise from the lateral intermuscular septum actually occupy a *more lateral position*, during contraction, than those of the lateral head. The fibres of the medial head are inserted partly into the olecranon and partly into the deep part of the flattened tendon described above. A few fibres are inserted into the posterior part of the capsule of the elbow joint to prevent its being nipped in extension of the forearm (cf. articularis genu).

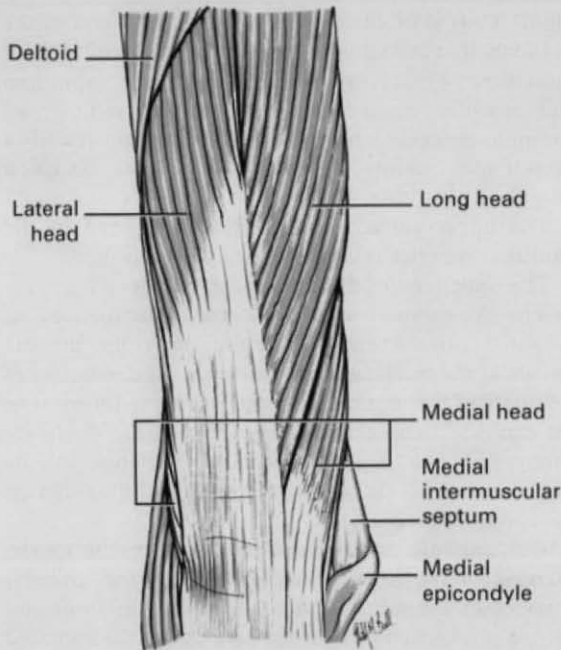


Fig. 2.24 Left triceps from behind. The medial head extends to the lateral margin at the lower end of the muscle.

Nerve supply. By the radial nerve (C7, 8), by four branches; the medial head receives two. In order from above downwards the branches go to the long, medial, lateral and medial heads, and they arise before the radial nerve makes contact with the bone of the radial groove (see below). Fractures of the middle of the shaft of the humerus, even though they may damage the radial nerve, are not likely to cause paralysis of triceps because of the high origin of the branches.

Action. The muscle is the extensor of the elbow joint, especially when speed and power are needed. The long head is an important factor in stabilizing the abducted shoulder joint to supplement gravity, and it aids in extending the shoulder joint (p. 77).

Test. With the arm abducted to a right angle, the flexed forearm is extended against resistance and the muscle seen and felt. The arm must be abducted at the shoulder otherwise gravity will help to extend the flexed forearm.

Radial nerve

Leaving the axilla as described on page 69 the nerve (Fig. 2.15) accompanies the profunda brachii vessels and spirals obliquely downwards behind the humerus from medial to lateral, lying for the most part *behind* the uppermost fibres of the medial head of triceps which

separates it from the bone. Only at the lateral edge of the humerus is the nerve in contact with the periosteum of the lower end of the radial groove (often called the spiral groove), so that contrary to popular belief it does not occupy the *whole* length of the groove. The uppermost fibres of origin of brachialis cover the lowest part of the groove, and in this region the nerve pierces the lateral intermuscular septum to enter the anterior compartment and so reach the cubital fossa where it lies under cover of brachioradialis (Fig. 2.30). Before reaching the humerus the nerve has already given off two of its four branches to triceps (to the long and medial heads) and the posterior cutaneous nerve of arm (p. 69). Behind the humerus it gives off the branch to the lateral head and another to the medial head which continues down through triceps to supply anconeus. The main nerve also gives origin to the lower lateral cutaneous nerve of the arm and the posterior cutaneous nerve of the forearm. It is characteristic of the radial nerve to give off its branches at a level considerably proximal to the part to be innervated.

The nerve is easily palpated (feel your own!). It can be rolled on the humerus beneath the finger tip one-third of the way down from the deltoid tuberosity to the lateral epicondyle.

The *surface marking* of the nerve is from the point where the posterior wall of the axilla and arm meet to a point two-thirds of the way along a line from the acromion to the lateral epicondyle, and thence to the front of the epicondyle.

Profunda brachii artery

This is the vessel of supply to the triceps. At the lateral intermuscular septum it divides into anterior and posterior branches; only the former pierces the septum. Each runs downwards, in front of and behind the elbow, to join the cubital anastomosis (Fig. 2.34).

Ulnar nerve

The nerve courses through the lower part of the extensor compartment and disappears into the forearm by passing between the humeral and ulnar heads of origin of flexor carpi ulnaris (Fig. 2.41). It lies in contact with the bone in the groove behind the medial epicondyle, then lies against the medial ligament of the elbow joint, to which it gives a twig of supply.

ELBOW JOINT

This is a synovial joint of the hinge variety between the lower end of the humerus and the upper ends of radius

and ulna (Figs 2.25–2.28). It communicates with the proximal radioulnar joint, in contrast to the wrist, which does not communicate with the distal radioulnar joint.

The lower end of the **humerus** shows the prominent conjunction of capitulum and trochlea (Fig. 2.25). The *capitulum*, for the head of the radius, is a portion of a sphere. It projects forward, and also downwards, where its lower border lies at the distal extremity of the humerus. In contrast the *trochlea*, which lies medial, is a grooved surface that extends around the lower end of the humerus to the posterior surface of the bone. The groove of the trochlea is limited medially by a sharp and prominent ridge and laterally by a lower and blunter ridge that blends with the articular surface of the capitulum.

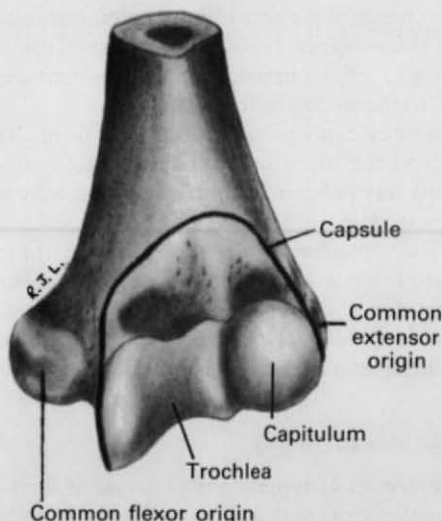


Fig. 2.25 Lower end of the left humerus, showing the line of attachment of the capsule of the elbow joint. (For the posterior view, see Fig. 2.62.)

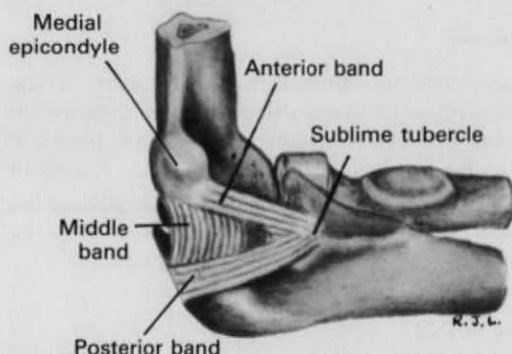


Fig. 2.26 Ulnar collateral (medial) ligament of the left elbow joint, showing its three constituent bands.

ulum. Thus is produced a tilt on the lower end of the humerus that accounts in part for the carrying angle of the elbow. Fossae immediately above the capitulum and trochlea receive the head of the radius and coronoid process of the ulna in full flexion; posteriorly a deep fossa receives the olecranon in full extension (Fig. 2.62).

The upper surface of the cylindrical head of the **radius** is spherically concave to fit the capitulum.

The upper end of the **ulna** shows the deep trochlear notch. A curved ridge joins the prominences of coronoid process and olecranon; the ridge fits the groove in the trochlea of the humerus. The obliquity of the shaft of the ulna to this ridge accounts for most of the carrying angle at the elbow (Fig. 2.63). There are commonly two separate articular surfaces in the trochlear notch, one on the olecranon and the other on the coronoid process.

The **capsule** is attached to the humerus at the margins of the lower rounded ends of the articular surfaces of capitulum and trochlea, but in front and behind it is carried up over the bone above the coronoid and olecranon fossae (Figs 2.26 and 2.62). Distally, the capsule is attached to the trochlear notch of the ulna at the edge of the articular cartilage, and to the annular ligament of the proximal radioulnar joint (Fig. 2.28). It is not attached to the radius.

The capsule and annular ligament are lined with *synovial membrane*, which is attached to the articular margins of all three bones. The synovial membrane thus floors in the coronoid and olecranon fossae on the lower end of the humerus, and bridges the gap between the radial notch of the ulna and the neck of the radius. The quadrate ligament (p. 95) prevents herniation of the synovial membrane between the anterior and posterior free edges of the annular ligament.

The **ulnar collateral (medial) ligament** of the elbow joint is triangular (Fig. 2.26) and consists of three bands. The *anterior band* is the strongest. It passes from the medial epicondyle of the humerus to a small tubercle (unnamed but previously called the sublime tubercle) on the medial border of the coronoid process. The *posterior band* joins the sublime tubercle and the medial border of the olecranon. A *middle band* connects these two and lies more deeply; it lodges the ulnar nerve on its way from the arm to the forearm (Fig. 2.27). The **radial collateral (lateral) ligament** (Fig. 2.28) is a single flattened band attached to the humerus below the common extensor origin; it fuses with the annular ligament of the head of the radius. The anterior and posterior ligaments are merely thickened parts of the capsule. The **annular ligament** is attached to the margins of the radial notch of the ulna, and clasps

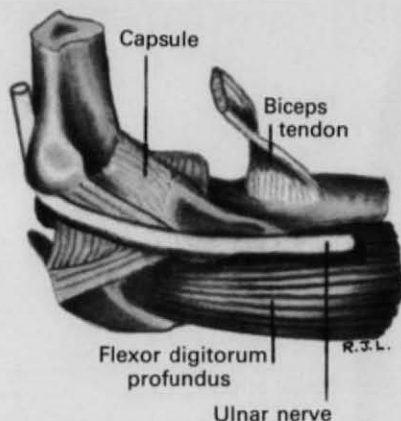


Fig. 2.27 Left elbow joint from the medial side, with the ulnar nerve lying against the 'sublime' tubercle (compare with Fig. 2.26).

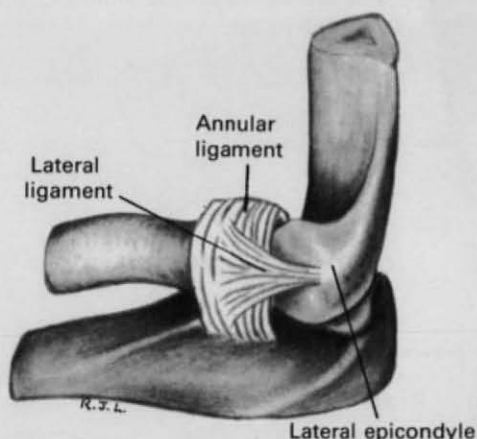


Fig. 2.28 Radial collateral (lateral) ligament of the left elbow joint, passing from the lateral epicondyle to the annular ligament.

the head and neck of the radius in the proximal radioulnar joint. It has no attachment to the radius, which remains free to rotate in the annular ligament.

Nerve supply. By the musculocutaneous, median, ulnar and radial nerves (Hilton's law).

Movements

The only appreciable movement possible at the elbow joint is the simple hinge movement of *flexion* and *extension*. From the straight (extended) position the range of flexion is about 140° . This movement does not take place in the line of the humerus, for the axis of the hinge lies obliquely. The extended ulna makes with the

humerus an angle of about 170° . This so-called 'carrying-angle' fits the elbow into the waist when the arm is at the side, and it is significant that the obliquity of the ulna is more pronounced in women than in men. However, the line of upper arm and forearm becomes straightened out when the forearm is in the usual working position of almost full pronation (Fig. 2.35). A pathological increase in this 'valgus' angle (e.g. from a fractured lateral epicondyle or damaged epiphysis) may gradually stretch the ulnar nerve behind the medial epicondyle and cause an ulnar nerve palsy. During pronation-supination of the forearm there is some rocking movement of the ulna on the trochlea (p. 96). In extension the tip of the olecranon lies in line with the humeral epicondyles, but in full flexion these three bony points make an equilateral triangle.

Surgical approach

The commonest approaches are from the sides. Medially the ulnar nerve is displaced backwards and the common flexor origin detached to expose the capsule, while on the lateral side the common extensor origin can be similarly detached. On this side the capsule incision must not extend lower than the level of the head of the radius to avoid damage to the posterior interosseous nerve as it winds round the shaft within the supinator.

For aspiration or injection the needle is inserted on the posterolateral side above the head of the radius, with the elbow at a right angle. The medial side is avoided because of the ulnar nerve.

PART 7

ANTERIOR COMPARTMENT OF THE FOREARM

The flexor muscles in the forearm are arranged in two groups, superficial and deep. The five muscles of the superficial group cross the elbow joint; the three muscles of the deep group do not. The flexor compartment is much more bulky than the extensor compartment, for the necessary power of the grip. The extensor muscles merely release the grip.

SUPERFICIAL MUSCLES

These five muscles (Fig. 2.29) are distinguished by the fact that they possess a common origin from the medial epicondyle of the humerus, at its anterior surface.

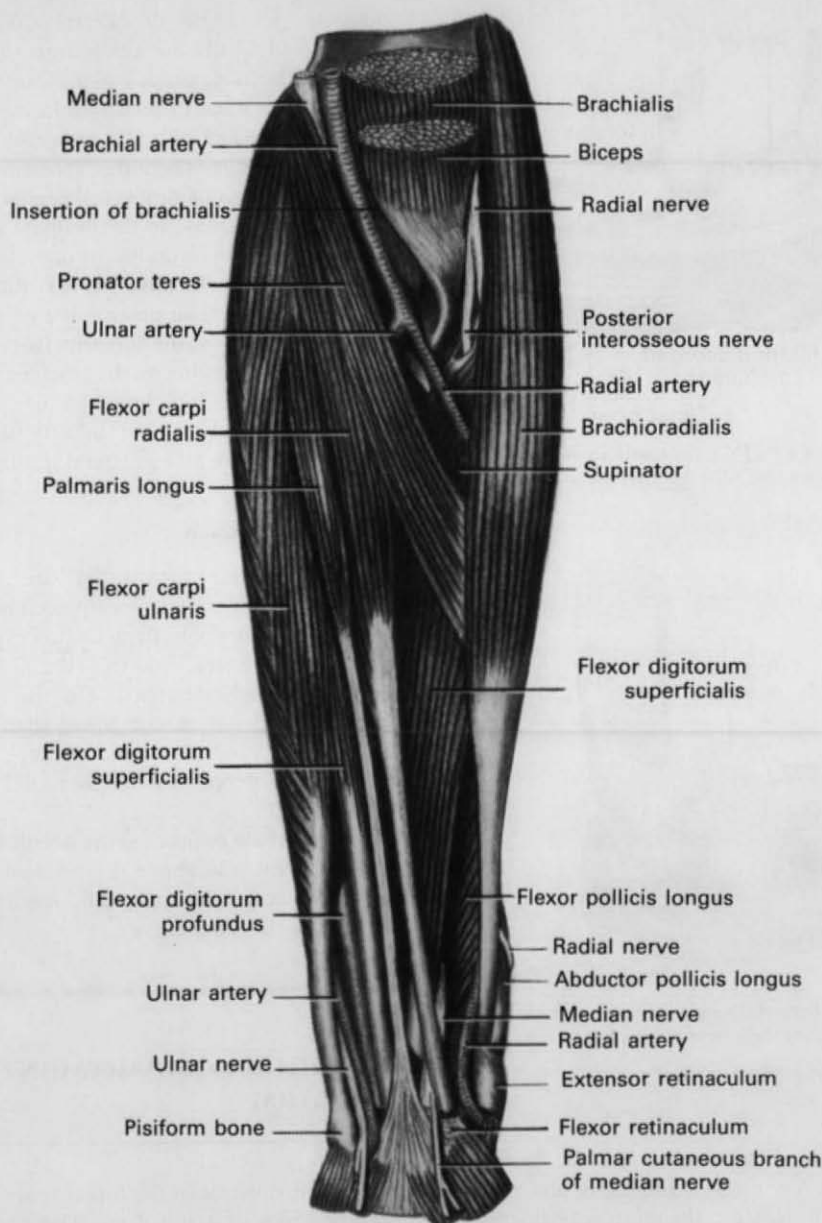


Fig. 2.29 Superficial muscles of the flexor compartment of the left forearm. Brachioradialis has been retracted laterally to show the radial nerve and its posterior interosseous branch, and the brachial artery and median nerve have been displaced medially to show the insertion of brachialis behind biceps.

Three of the group have additional areas of origin. The **common origin** attaches itself to a smooth area on the anterior surface of the medial epicondyle (Fig. 2.25); there is but little flesh attached to the humerus, for at this point the intermuscular septa and the muscles

themselves are fused into a tendinous mass. With the heel of the hand placed over the opposite medial epicondyle, palm lying on the forearm, the digits point down along the *five superficial muscles*—thumb for pronator teres, index for flexor carpi radialis, middle

finger for flexor digitorum superficialis, ring finger for palmaris longus, little finger for flexor carpi ulnaris.

Pronator teres

Arising from the common origin and from the lower part of the medial supracondylar ridge, the main superficial belly is joined by the small deep head, which arises from the medial border of the coronoid process of the ulna just distal to the sublime tubercle. The median nerve lies *between* the two heads and the ulnar artery passes deep to the deep head. The muscle, forming the medial border of the cubital fossa (Figs 2.29 and 2.30), runs distally across the front of the forearm to be inserted by a flat tendon into the most prominent part of the lateral convexity of the radius, between the lower ends of the anterior and posterior oblique lines. The attachment lies just *behind* the lateral profile of the radius (Fig. 2.64).

Nerve supply. By the first (highest) muscular branch of the median nerve (C6, 7), usually arising just below the level of the elbow joint but occasionally above it, in which case the median nerve may be said to have a muscular branch in the arm (p. 81).

Action. The muscle pronates the forearm and flexes the elbow. In simple pronation, the flexing action of the muscle requires opposition by triceps. Its oblique origin from the humerus is functional; it exerts an adducting pull on the radius (and thus on the ulna) to oppose the abduction of anconeus (p. 100). In radial nerve paral-

ysis it can be transplanted to the posterior compartment to extend the joint.

Test. From the supine position the forearm is pronated against resistance and the muscle palpated at the medial margin of the cubital fossa.

Flexor carpi radialis

Arising from the common origin the fleshy belly lies distal to pronator teres. In the middle of the forearm the flesh gives way to a flattened tendon which becomes rounded at the wrist, where it runs through its own compartment in the flexor retinaculum, and then lies in the groove of the trapezium. It passes beside the tendon of flexor pollicis longus and is inserted into the bases of the second and third metacarpals (symmetrically with extensors longus and brevis). Quite frequently it gives a slip of insertion into the scaphoid bone. The absence of fleshy fibres distinguishes the tendon above the wrist (Figs 2.29 and 2.31) from that of flexor pollicis longus, which is 'feathered' by fleshy fibres joining it from the radial side. The tendon is a prominent landmark towards the radial side of the front of the wrist. The radial artery lies lateral to the tendon and the median nerve (and the tendon of palmaris longus, if present) medial to it.

Nerve supply. By the median nerve (C6, 7).

Action. It is a flexor and radial abductor of the wrist and assists in pronation of the forearm and flexion of the elbow. It is an important stabilizer of the wrist in finger and thumb movements.

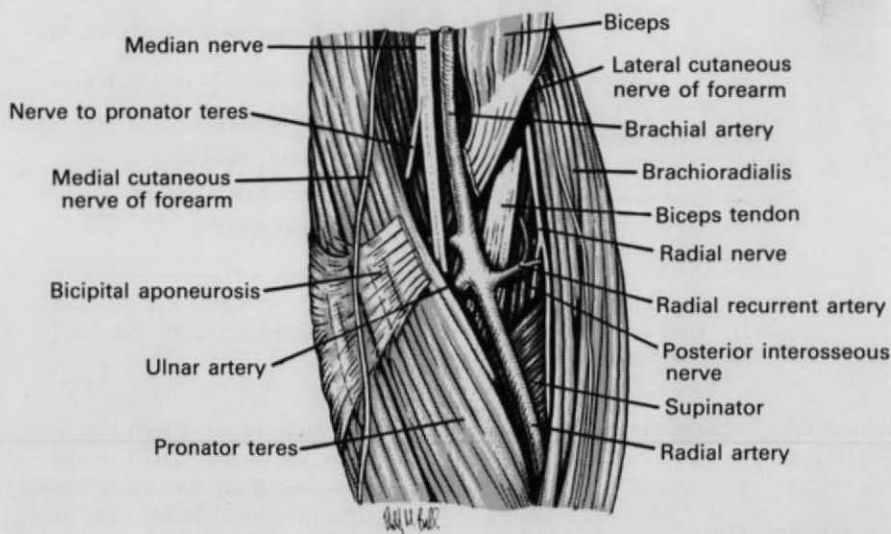


Fig. 2.30 Left cubital fossa. Medial to the tendon of biceps lie the brachial artery and then the median nerve; both are crossed by the bicipital aponeurosis (here partly removed). The lateral cutaneous nerve of the forearm emerges from beneath the lateral border of biceps where the muscle fibres become tendinous. The nerve to pronator teres has an unusually high origin.

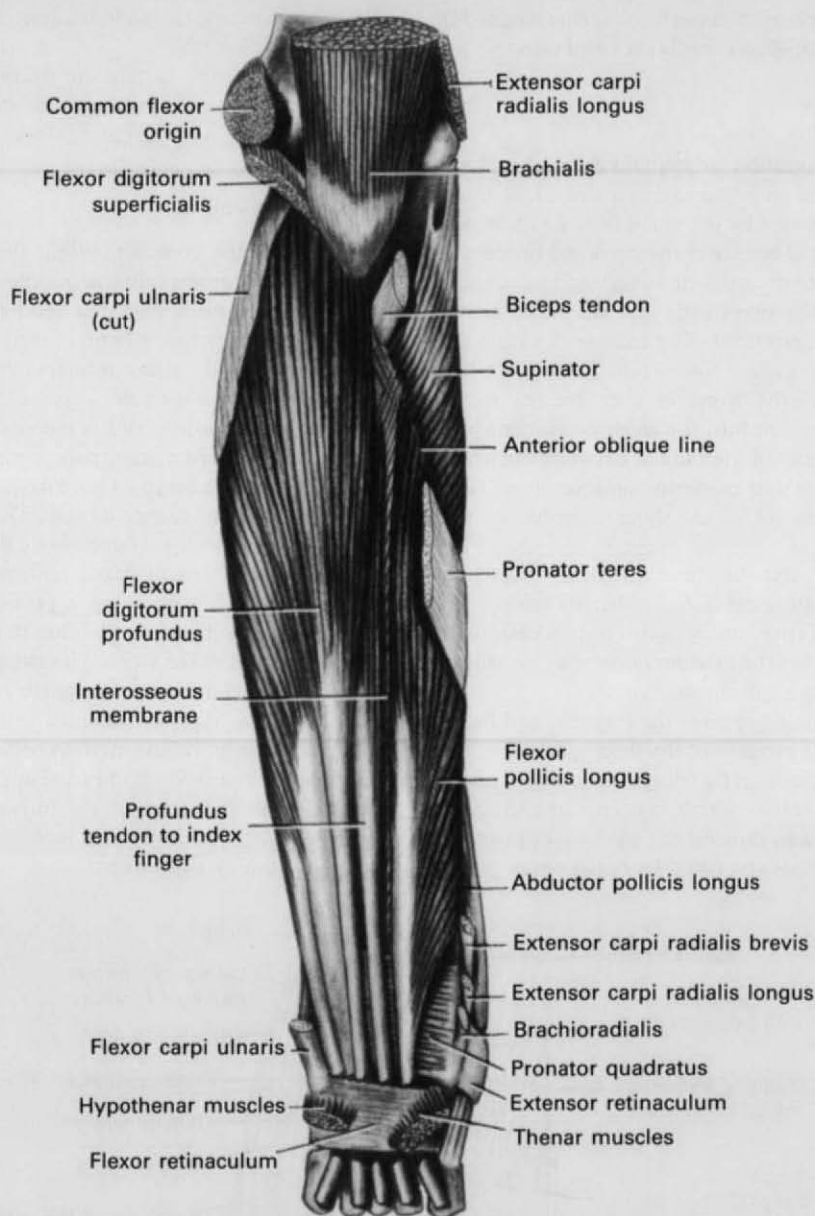


Fig. 2.31 Deep muscles of the flexor compartment of the left forearm. The flexor retinaculum remains in place at the wrist.

Test. The wrist is flexed against resistance and the tendon is easily seen and felt.

Flexor digitorum superficialis

It arises from the common origin, the medial ligament of the elbow joint, and the sublime tubercle on the medial border of the coronoid process of the ulna

(humero-ulnar head). From this point a fibrous arch continues the origin across to the radius, where the muscle arises from the whole length of the anterior oblique line (radial head). The fleshy belly is partly hidden above by the other superficial flexors, and is therefore frequently described as being in an intermediate layer. Its oblique origin, in continuity from the medial epicondyle to the insertion of pronator teres,

forms the upper limit of the space of Parona (p. 92). Above the wrist the tendons appear on each side of the palmaris longus tendon. The flesh which gives rise to the tendons for the middle and ring fingers is superficial across the wide origin of the muscle. That giving rise to the tendons of the index and little fingers arises more deeply from the common flexor origin and ulnar collateral (medial) ligament of the elbow. It lies beneath the belly for the middle two fingers, and is divided by a transverse tendinous intersection into an upper and two lower bellies. The tendons pass in the above order beneath the flexor retinaculum, i.e. those to the middle and ring fingers superficial to those to the index and little finger (Fig. 2.46). Their course in the palm and insertion into the middle phalanges is considered on page 117. In the forearm the muscle has the median nerve plastered to its deep surface by areolar tissue (Fig. 2.32); the commencing profundus tendon for the index finger can readily be mistaken for the nerve at operation or in a dissection.

Nerve supply. By the median nerve (C7, 8).

Action. It is a flexor of the proximal interphalangeal joints, and secondarily of the metacarpophalangeal and

wrist joints. It also assists in flexion of the elbow and wrist.

Test. The fingers are flexed at the proximal interphalangeal joints against resistance applied to the middle phalanges (but remember that flexor digitorum profundus can also flex these joints).

Palmaris longus

Functionally negligible, this muscle is of morphological interest. It is absent in 13% of arms. It is phylogenetically degenerating and shows the characteristics of this, i.e. short belly and long tendon (like plantaris in the leg). Replacement of its distal tendon by ligament (palmar aponeurosis) is a further characteristic of degeneration (like coccygeus and the sacrospinous ligament). It is supposed that the muscle once existed as a flexor of the proximal phalanges, with its tendons lying in the palm superficial to those of flexor digitorum superficialis, and splitting around them to be attached to the proximal phalanges. The muscle arises from the common origin and its tendon (Fig. 2.29) is inserted, adherent across the front of the flexor retinaculum,

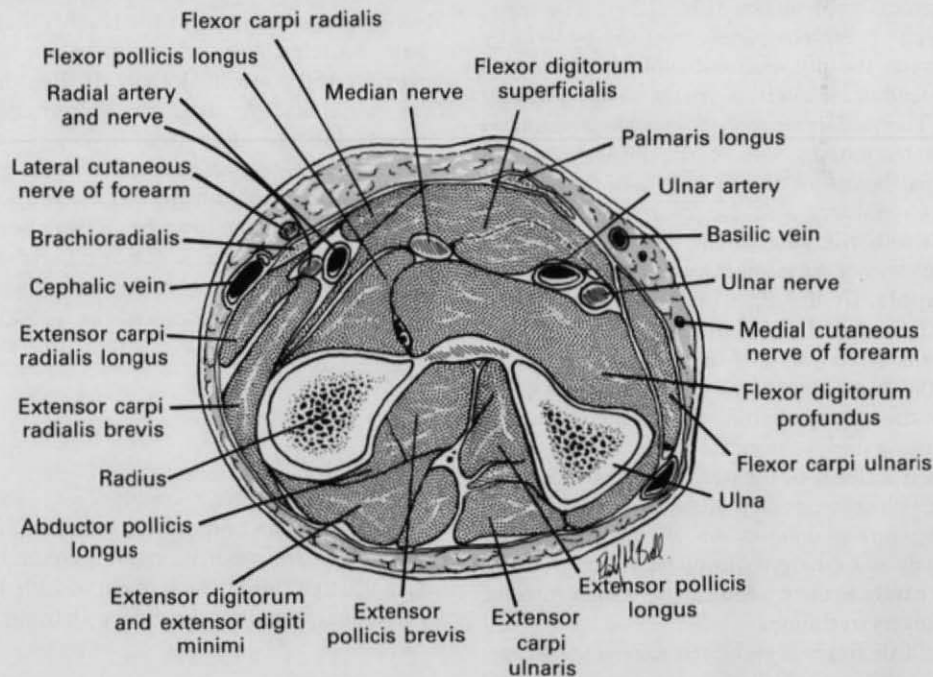


Fig. 2.32 Cross-section through the middle of the right forearm, looking towards the elbow. The median nerve adheres to the deep surface of flexor digitorum superficialis, and the ulnar nerve and artery are under cover of the muscle more medially. The superficial branch of the radial nerve and the radial artery are under cover of brachioradialis. The deep (posterior interosseous) branch of the radial nerve has divided above this level to supply extensor muscles.

into the palmar aponeurosis. The main importance of the muscle is that its tendon slightly overlaps the median nerve from the ulnar side, and it must not be mistaken for the nerve (p. 94).

Nerve supply. By the median nerve (C7, 8).

Action. It is a weak flexor of the wrist, and by its attachment to the palmar aponeurosis it may produce minimal flexion at the metacarpophalangeal joints of the fingers. In radial nerve paralysis the tendon can be transplanted to abduct the thumb.

Test. The wrist is flexed and the tendon palpated when the pads of the thumb and little finger are pinched together (to help fix the wrist and so make the tendon stand out).

Flexor carpi ulnaris

Arising from the common origin the muscle receives a further contribution from a wide aponeurosis which arises from the medial border of the olecranon and the upper three-fourths of the subcutaneous border of the ulna. This aponeurosis lies superficial to the belly of flexor digitorum profundus — the latter gives the bulk to the medial side of the upper forearm. It lies edge to edge, at the subcutaneous border of the ulna, with the aponeurosis of extensor carpi ulnaris (Fig. 2.39). The ulnar nerve enters the flexor compartment of the forearm by passing between the humeral and ulnar heads of this muscle. Its tendon of insertion passes to the pisiform (Fig. 2.29). The pisiform is morphologically a sesamoid bone in the tendon; by way of the pisohamate and pisometacarpal ligaments the muscle acts on a wider insertion. Its symmetry with the insertion of extensor carpi ulnaris into the base of the fifth metacarpal is maintained by way of the pisometacarpal ligament.

Nerve supply. By the ulnar nerve (C7, 8) through two to four branches. In 95% of cases the fibres have come from the lateral cord of the brachial plexus, or rarely from the middle trunk by a communication in the axilla; this is the contribution from C7 (the rest of the ulnar nerve being derived from C8, T1).

Action. It is a flexor of the wrist, an ulnar adductor when acting with extensor carpi ulnaris, and a fixator of the pisiform during contraction of the hypothenar muscles. It acts as a synergist during wrist extension. In radial nerve paralysis the tendon can be transplanted to extend the fingers or thumb.

Test. The little finger is abducted against resistance; this fixes the pisiform which gives origin to abductor digiti minimi, and the tendon of flexor carpi ulnaris can be seen and palpated proximal to the bone. Alternatively the wrist can be flexed and adducted against resistance.

CUBITAL FOSSA

The **cubital fossa** is the triangular area between pronator teres, brachioradialis and a line joining the humeral epicondyles (Fig. 2.30). It possesses a roof and floor, and certain structures pass through it. The **roof** is formed by the deep fascia of the forearm, reinforced on the medial side by the bicipital aponeurosis. On the bicipital aponeurosis lies the median basilic vein with the medial cutaneous nerve of the forearm on its medial side; the aponeurosis separates these structures from the underlying median nerve and brachial artery. Laterally on the roof lie the lateral cutaneous nerve of the forearm and the median cephalic vein. The **floor** is formed in the main by the brachialis muscle; below and laterally the supinator clasps the neck of the radius.

The **contents** of the fossa, from medial to lateral side, are the **median nerve**, **brachial artery**, and the **tendon of biceps**. Farther laterally are the radial nerve and its posterior interosseous branch, but these are only seen when brachioradialis is retracted laterally (Fig. 2.30). The artery is palpated here medial to the tendon to define the position for placing the stethoscope when taking the blood pressure. The further courses of the brachial artery and median nerve are discussed below (pp. 92 and 94). The **radial nerve**, having given branches to the brachialis and brachioradialis muscles, lower down gives another branch to extensor carpi radialis longus. It then divides into its two terminal branches, the superficial (cutaneous) branch and the deep branch, commonly called the posterior interosseous nerve. The latter gives branches to extensor carpi radialis brevis and supinator and disappears from the fossa by passing between the two heads of origin of the supinator muscle (Figs 2.29 and 2.30). The superficial branch passes down the forearm under cover of the brachioradialis (p. 98) and the posterior interosseous nerve enters the extensor compartment (p. 103).

DEEP MUSCLES

The group consists of flexor digitorum profundus, flexor pollicis longus and pronator quadratus (Fig. 2.31). The two former are subdivisions of a common deep flexor from which a third (which might be called flexor indicis profundus) appears to be phylogenetically emerging.

Flexor digitorum profundus

The most powerful and the bulkiest of the forearm muscles, it arises by fleshy fibres from the medial surface of the olecranon (Fig. 2.27), from the upper three-

fourths of the medial and anterior surfaces of the ulna as far distally as pronator quadratus, and from a narrow strip of interosseous membrane. The tendon for the index separates in the forearm; the three other tendons are still partly attached to each other as they pass across the carpal bones in the flexor tunnel and do not become detached from each other until they reach the palm (Fig. 2.31). At this point of separation the four lumbricals take origin. They are described in the section on the hand (p. 112).

Nerve supply. By the anterior interosseous branch of the median nerve and by the ulnar nerve (C7, 8). Characteristically these nerves share equally; the bellies which merge into the tendons for index and middle fingers being supplied from the median, the ring and little fingers from the ulnar nerves. The corresponding lumbricals are similarly supplied.

This distribution of 2:2 between median and ulnar nerves occurs in only 60% of individuals. In the remaining 40% the median and ulnar distribution is 3:1 or 1:3 equally (20% each). Whatever the variation, however, the rule is that each lumbrical is supplied by the same nerve which innervates the belly of its parent tendon.

Action. It flexes the terminal interphalangeal joints and, still acting, rolls the fingers and wrist into flexion. It is the great gripping muscle. Extension of the wrist is indispensable to the full power of contraction of the muscle (Fig. 2.55).

Test. With the fingers extended and the hand lying supine on the table, the distal interphalangeal joints are flexed against resistance with the middle phalanx held in extension.

Flexor pollicis longus

This muscle arises from the anterior surface of the radius below the anterior oblique line and above the insertion of pronator quadratus, and from an adjoining strip of interosseous membrane. Some fibres, arising in common with flexor digitorum superficialis, join the muscle from either the medial or the lateral border (or both) of the coronoid process of the ulna. The tendon forms on the ulnar side of this unipennate muscle; it should be noted that the tendon receives fleshy fibres into its radial side to a point just above the wrist, a useful point in distinguishing it from the flexor carpi radialis in window dissections or in wounds above the wrist (Fig. 2.31). The tendon passes in the carpal tunnel deep to that of the flexor carpi radialis, then spirals around its ulnar side to become superficial. It extends into the thumb to be inserted into the base of the distal phalanx.

Nerve supply. By the anterior interosseous branch of the median nerve (C8, T1).

Action. It is the only flexor of the interphalangeal joint of the thumb, and also flexes the metacarpophalangeal and carpometacarpal joints of the thumb and the wrist joint.

Test. With the proximal phalanx of the thumb held steady, the distal phalanx is flexed against resistance.

Pronator quadratus

Arising from the lower fourth of the ulna, especially from the sinuous ridge on its anteromedial aspect, the fibres are inserted, superficially into the ridge on the anterolateral border of the radius above the styloid process (Fig. 2.33), more deeply into the anterior surface of the lower end of the radius, and most deeply into the triangular interosseous area just above the ulnar notch. The interosseous membrane clings to the posterior border of this triangular area, the sacciform recess of the distal radioulnar joint lies just in front of it, and the muscle is inserted into the remainder of the area.

Nerve supply. By the anterior interosseous branch of the median nerve (C8, T1).

Action. The muscle pronates the forearm and helps



Fig. 2.33 Deep structures in front of the right wrist. The anterior interosseous artery pierces the interosseous membrane at the upper border of pronator quadratus. The deep palmar arch is formed by the end of the radial artery anastomosing with the deep branch of the ulnar artery.

to hold the lower ends of the radius and ulna together, especially when the hand is weight-bearing. As a pronator it is more powerful than pronator teres, since its fibres run transversely and not obliquely. The muscle is too deep to be palpated.

Space of Parona

In front of pronator quadratus and deep to the long flexor tendons of the fingers is a space into which the proximal parts of the flexor synovial sheaths protrude. The space is limited proximally by the oblique origin of flexor digitorum superficialis. The space becomes involved in proximal extensions of synovial sheath infections; it can easily be drained through radial and ulnar incisions to the side of the flexor tendons.

NEUROVASCULAR PATTERN IN THE FOREARM

The general arrangement of the deep arteries and nerves of the forearm is that a nerve runs down each border of the forearm (radial and ulnar nerves), and the brachial artery divides into branches (radial and ulnar arteries) that run down to approach these nerves but do not cross them. The median nerve, on the deep surface of flexor superficialis, crosses the ulnar artery to lie between the two. Radial and ulnar arteries supply the hand; they run down directly into deep and superficial palmar arches. The arterial supply for the forearm comes from the common interosseous branch of the ulnar, which divides into posterior and anterior interosseous arteries. The posterior interosseous artery is rather a failure. Assisted at first by branches of the anterior interosseous that pierce the interosseous membrane, it later fails and is replaced by the anterior interosseous artery, which pierces the membrane to enter the extensor compartment (Fig. 2.33). Anterior (from median) and posterior (from radial) interosseous nerves, on the other hand, remain in their own compartments right down to the wrist, supplying muscles, periosteum and carpal ligaments. Neither nerve reaches the skin.

Three nerves share in the supply of the muscles of the forearm and each nerve passes between the two heads of a muscle. The median nerve passes between the two heads of pronator teres and the ulnar nerve between the two heads of flexor carpi ulnaris. These two nerves share in the supply of the muscles of the flexor compartment. The muscles of the extensor compartment are supplied by the posterior interosseous nerve, which enters the compartment by passing between the two layers of the supinator muscle.

VESSELS OF THE FLEXOR COMPARTMENT

The brachial artery enters the forearm by passing into the cubital fossa in the midline; halfway down the fossa it divides into radial and ulnar arteries (Fig. 2.34). The radial usually appears to be the direct continuation of the brachial artery, whereas the ulnar branches off almost at a right angle (Fig. 2.30).

Radial artery

The **radial artery** passes distally medial to the biceps tendon, across the supinator, over the tendon of insertion of the pronator teres, the radial origin of flexor digitorum superficialis, the origin of the flexor pollicis longus, the insertion of pronator quadratus and the lower end of the radius (Fig. 2.33). It disappears beneath the tendons of abductor pollicis longus and extensor pollicis brevis to cross the anatomical snuff box (Fig. 2.42). In the upper part of the forearm it is overlapped anteriorly by brachioradialis (Fig. 2.29). In

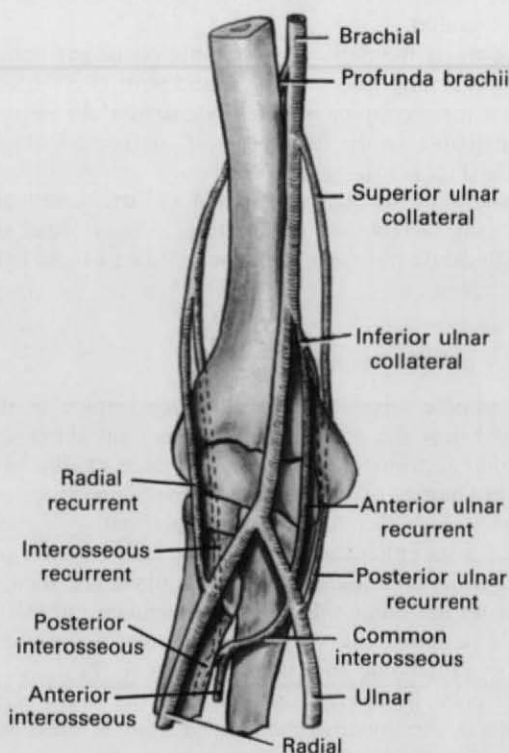


Fig. 2.34 Anastomoses at the right elbow. The brachial artery gives off the profunda and the superior and inferior ulnar collateral arteries, which anastomose with the recurrent branches from the radial, ulnar and posterior interosseous arteries.

the middle third of its course it has the radial nerve lateral to it.

The *surface marking* of the artery is along a line, slightly convex laterally, from medial to the biceps tendon in the cubital fossa to a point medial to the styloid process of the radius. It can be surgically exposed at its lower end (p. 92) which is the commonest site for arterial *cannulation*. The small size of the vessel predisposes to thrombosis (which is rare when the femoral artery is used, p. 155); air embolus is a possible complication.

Ulnar artery

The **ulnar artery** disappears from the cubital fossa by passing deep to the deep head of pronator teres and beneath the fibrous arch of the flexor digitorum superficialis near the median nerve. It then leaves the median nerve and lies on flexor digitorum profundus with the ulnar nerve to its ulnar side and passes down over the front of the wrist into the palm, where it continues as the superficial palmar arch (p. 110). Ulnar artery pulsation can be felt on the radial side of the tendon of flexor carpi ulnaris just above the pisiform bone.

The *surface marking* is along a line, slightly convex medially, from medial to the biceps tendon in the cubital fossa to the radial side of the pisiform. It can be surgically *exposed* at the lower end and followed upwards by displacing flexor carpi ulnaris. Beware of the ulnar nerve on the ulnar side of the artery!

Its chief branch is the **common interosseous** (Fig. 2.34), which divides into anterior and posterior interosseous branches. The **anterior interosseous artery** lies deeply on the interosseous membrane between flexor digitorum profundus and flexor pollicis longus, supplying each. Perforating branches pierce the interosseous membrane to supply the deep extensor muscles. Nutrient vessels are given to both radius and ulna. The artery passes posteriorly through the interosseous membrane at the level of the upper border of pronator quadratus (compare with the peroneal artery in the leg) (Fig. 2.33).

The **posterior interosseous artery** disappears by passing backwards through the interosseous space above the upper end of the interosseous membrane but distal to the oblique cord (compare with the anterior tibial artery in the leg).

Anastomosis around the elbow joint

Recurrent branches, in some cases double, arise from radial, ulnar and interosseous arteries and run upwards both anterior and posterior to the elbow joint, to

anastomose with descending articular branches of the profunda brachii, and the ulnar collateral arteries (Fig. 2.34).

Anastomosis around the wrist joint

Both radial and ulnar arteries give off anterior and posterior carpal branches. These anastomose with each other deep to the long tendons, forming the anterior and posterior carpal arches. The **anterior carpal arch** lies transversely across the wrist joint (Fig. 2.33); it supplies the carpal bones and sends branches distally into the hand to anastomose with the deep palmar arch. The **posterior carpal arch** lies transversely across the distal row of carpal bones (p. 105). It sends dorsal metacarpal arteries distally into each metacarpal space; these divide to supply the fingers and they anastomose through the interosseous spaces with the palmar digital and metacarpal branches of the palmar arches. Thus a free anastomosis is established between radial and ulnar arteries through the carpal and palmar arches (Fig. 2.33).

Veins of the forearm

The **deep veins** are plentiful and accompany the arteries, usually by double *venae comitantes* which anastomose freely with each other. They drain the forearm but bring relatively little blood from the hand.

Most of the blood from the palm of the hand passes through to a superficial venous network on the dorsum. From the radial side of this arch the **cephalic vein** begins in the anatomical snuffbox and runs up along the preaxial border of the limb (Fig. 2.23). It runs in the upper arm lateral to biceps, in the deltopectoral groove, and perforates the clavipectoral fascia to drain into the axillary vein. From the ulnar side of the dorsal venous arch the **basilic vein** runs up the postaxial border of the limb. It pierces the deep fascia halfway between elbow and axilla (Fig. 2.23) and joins the brachial veins to form the axillary vein.

The **median forearm vein** drains subcutaneous tissue of the front of the wrist and forearm. It divides at the elbow into *median cephalic* and *median basilic*; the latter receives a deep vein. These two veins open into the cephalic and basilic veins respectively (Fig. 2.23). The deep communicating vein joins the median basilic vein and makes it a larger vessel than the median cephalic. The median cephalic is much less movable in the subcutaneous tissues than the median basilic, and therefore is often more convenient to use in intravenous therapy in spite of its smaller size. There are frequent variations from the standard patterns just described.

Lymphatics of the forearm

As elsewhere in the body the superficial lymphatics follow veins, the deep ones follow arteries. From the ulnar side of the hand and forearm the subcutaneous lymphatics run alongside the basilic vein to the supra-trochlear nodes. From the radial side the lymphatics run alongside the cephalic vein to the deltopectoral and infraclavicular nodes. From the deep parts of the hand and forearm and from the supra-trochlear nodes lymphatics pass to the lateral group of axillary nodes.

NERVES OF THE FLEXOR COMPARTMENT

The **lateral cutaneous nerve of the forearm**, the cutaneous continuation of the musculocutaneous nerve, pierces the deep fascia above the elbow lateral to the lower end of biceps (where the muscle fibres become tendinous), and supplies the preaxial border of the forearm, by anterior and posterior branches, as far distally as the ball of the thumb. The **medial cutaneous nerve of the forearm** is roughly symmetrical with the lateral cutaneous nerve, supplying the postaxial border of the forearm by anterior and posterior branches as far distally as the wrist. Their areas of cutaneous distribution meet at the anterior axial line (p. 23), where there is minimal overlap (Fig. 2.57).

The superficial branch of the **radial nerve**, the cutaneous continuation of the main nerve, runs from the cubital fossa on the surface of supinator, pronator teres tendon and flexor digitorum superficialis on the lateral side of the forearm under cover of brachioradialis. While under cover it lies on the radial side of the radial artery. It leaves the flexor compartment of the forearm by passing backwards under the tendon of brachioradialis a few centimetres above the radial styloid, and breaks up into two or three branches which can be rolled on the surface of the tautened tendon of extensor pollicis longus. They are distributed to the radial two-thirds of the dorsum of the hand and the proximal parts of the dorsal surfaces of thumb, index, middle and half of the ring fingers (Fig. 2.43), but see page 126 for the effects of nerve injury.

The **median nerve**, while still in the cubital fossa, gives a branch to pronator teres then disappears between the two heads of that muscle. Beyond the muscle it supplies flexor carpi radialis and palmaris longus, and then joins the ulnar artery at the fibrous arch of the superficial flexor. Deep to flexor digitorum superficialis it passes distally in the midline of the forearm closely attached by areolar tissue to the deep surface of the muscle, which it supplies. It emerges from the lateral border of the muscle (Fig. 2.29),

between palmaris longus and flexor carpi radialis tendons, and is slightly overlapped from the ulnar side by the tendon of palmaris longus before passing beneath the flexor retinaculum to enter the hand (p. 111). At the wrist the nerve is not round but flattened. It is nourished by the **median artery**, a branch of the anterior interosseous which was the original axial artery of the fetal limb. It may persist as a large vessel. Small twigs from it on the surface of the nerve help at operation to distinguish the nerve from adjacent tendons.

The median nerve gives off an **anterior interosseous** branch which runs down with the artery of the same name and supplies flexor digitorum profundus (usually the bellies which move index and middle fingers), flexor pollicis longus and pronator quadratus, also the interosseous membrane and the periosteum of the radius and ulna. It ends in the anterior part of the capsule of the wrist joint and the carpal joints, which it supplies. It has no cutaneous branch.

Just above the flexor retinaculum the median nerve gives off a **palmar branch** to the skin over the thenar muscles.

The *surface marking* of the nerve is along a line from the point in the middle of the cubital fossa medial to the (palpable) brachial artery to a point at the wrist on the ulnar side of the tendon of flexor carpi radialis.

The **ulnar nerve** enters the forearm from the extensor compartment by passing between the humeral and ulnar heads of origin of flexor carpi ulnaris. It is more easily compressed against the medial surface of the coronoid process (Fig. 2.27) than against the humerus where it lies behind the medial epicondyle (Fig. 2.39). In the forearm the nerve lies under cover of the flattened aponeurosis of flexor carpi ulnaris with the ulnar artery to its radial side. This neurovascular bundle lies on flexor digitorum profundus. Branches of supply are given to flexor carpi ulnaris and the ulnar half (usually) of flexor digitorum profundus. The branch to flexor carpi ulnaris contains C7 fibres brought to the ulnar nerve in the axilla (p. 90); the branch to flexor digitorum profundus contains C8 and T1 fibres.

The ulnar nerve and ulnar artery emerge from beneath the tendon of flexor carpi ulnaris just proximal to the wrist (Fig. 2.29) and pass across the flexor retinaculum into the hand. Before emerging each gives off a dorsal branch which passes medially between the tendon of flexor carpi ulnaris and the lower end of the ulna. The dorsal branch of the ulnar nerve supplies the dorsum of the hand (Fig. 2.43) and of the ulnar one and a half fingers proximal to their nail beds. The dorsal branch of the ulnar artery enters the posterior

carpal arch. The small *palmar cutaneous branch* of the nerve runs down on the artery to pierce the deep fascia proximal to the flexor retinaculum, and supplies skin of the hypothenar eminence.

The *surface marking* of the nerve is along a line from the medial epicondyle of the humerus to the radial side of the pisiform bone.

RADIOULNAR JOINTS

The **proximal radioulnar joint** has been mentioned in connection with the elbow joint (p. 84). The essential structure here is the **annular ligament** which imprisons the head of the radius (Fig. 2.28). The annular ligament is attached to the radial notch of the ulna and its fibres encircle the head and *neck* of the radius. The ligament has no attachment to the radius, which is free to rotate within it. Superiorly it blends with the capsule of the elbow joint. The proximal radioulnar joint and the elbow joint form one continuous synovial cavity. The synovial membrane is attached to the radius at the lower margin of the cylindrical articular surface; it is supported between the ulna and the radius by the *quadrate ligament*. This stretches between the neck of the radius, proximal to the tuberosity, and the upper part of the supinator fossa of the ulna just distal to the radial notch. Its fibres run criss-cross, so that some are tense while others relax; its overall tension remains constant in all positions of supination and pronation.

The **distal radioulnar joint** is closed distally by a triangular fibrocartilage, which is attached by its base to the ulnar notch of the radius and by its apex to a small fossa at the base of the ulnar styloid. The **capsule** is loose and pouches upwards between the two bones behind the surface of the deep part of pronator quadratus, forming the *sacciform recess*. It is unusual for the fibrocartilage to be incomplete; in such rare cases, of course, the joint communicates with the wrist joint.

The **interosseous membrane** joins the interosseous borders of the two bones. Its fibres run from the radius down to the ulna at an oblique angle, so transmitting thrust from the wrist to the elbow via lower end of radius to upper end of ulna and so to the humerus. It tends to be relaxed when the weight is suspended from the hands; but in this case, of course, the weight is suspended by muscles, not by bones or ligaments. It is *taut in pronation* and lax in supination.

The *oblique cord* has been considered to represent a degenerated portion of either flexor pollicis longus or supinator. Its fibres run in opposite obliquity to those of the interosseous membrane. The cord slopes upwards

from just below the radial tuberosity to the side of the ulnar tuberosity, distal to the quadrate ligament. The posterior interosseous vessels pass through the gap between the oblique cord and the upper end of the interosseous membrane.

Nerve supplies. The proximal joint receives small twigs from the nerves of the elbow joint (p. 85), and the distal joint from the posterior interosseous (radial) and anterior interosseous (median) nerves.

Movements

Examine the articulated bones of the upper limb. The *basic* movements of pronation and supination are produced by movements of radius (and hand) around an immobile ulna. The axis around which the radius rotates obviously passes through the centre of curvature of each radioulnar joint. The *axis of pronation-supination* is oblique along the supinated forearm — it joins the centre of the head of the radius and the base of the styloid process of the ulna, and when prolonged passes near the little finger. It lies in the line of the shaft of the humerus, hence the carrying angle of the elbow (Fig. 2.35). For the ulna, as a result of the opposite curvatures of its upper and lower articular surfaces, must lie oblique to the axis of pronation-supination and therefore oblique to the shaft of the humerus, and this obliquity constitutes the carrying angle.

The axis of pronation-supination is fixed in relation to the ulna, but the *axis of the forearm itself* is not fixed in relation to the ulna. The axis of the forearm runs from the midpoint between the epicondyles of the humerus down to the midpoint between the styloid processes of the radius and ulna. The axis of the forearm is therefore constantly changing with the position of the bones throughout the range of pronation and supination. This can easily be seen by inspection of the dry bones and can be confirmed in the living forearm. It is illustrated in Figure 2.35. In supination the axis of the forearm is parallel with the ulna; it is oblique to the shaft of the humerus (carrying angle). In pronation the axis of the forearm crosses the ulna obliquely and lies parallel with the axis of pronation-supination; it is in line with the shaft of the humerus though the ulna has not moved. The carrying angle exists so that the forearm may be in line with the humerus in the working position, which is that of almost full pronation. Few acts except carrying are performed in the fully supinated position.

A simple experiment is worth performing. Flex the elbow to a right angle and lay the forearm on a table. Supination and pronation in this position are seen to

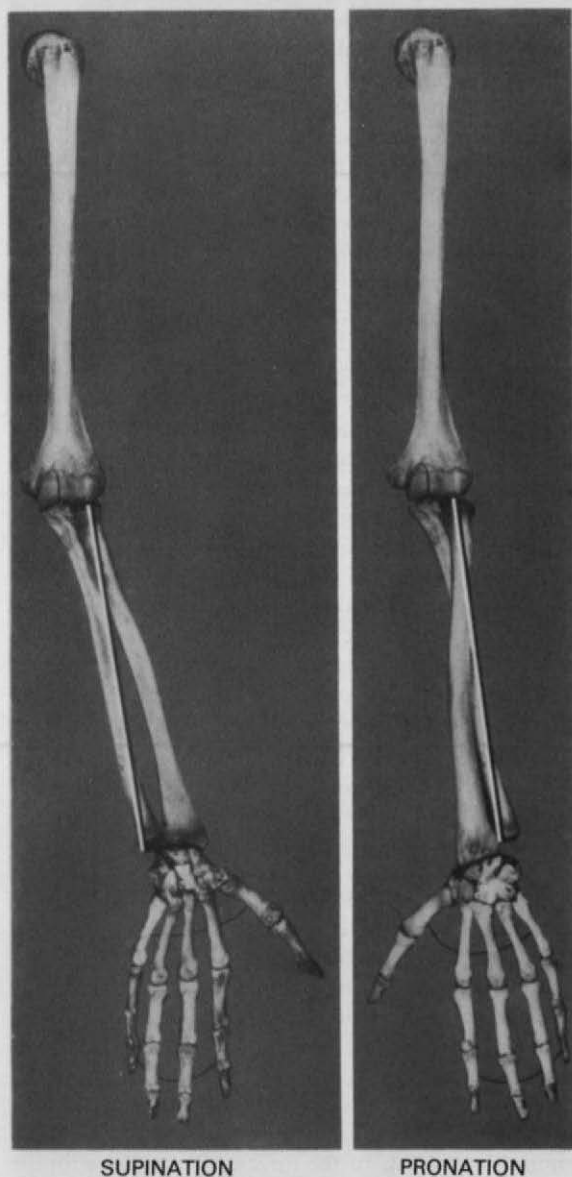


Fig. 2.35 Carrying angles of the left elbow and wrist. The limb bones are seen from the front and the axis of pronation-supination is indicated by the black lines; it is identical in both if the humerus does not move. In supination the third metacarpal lies parallel with the shaft of the humerus; the forearm lies oblique to these, making the carrying angles at the elbow and wrist. In pronation the axis of the forearm comes into line with the shaft of the humerus and with the axis of pronation-supination; the carrying angle at the elbow apparently disappears, though the ulna has not moved.

cause a wide movement of the thumb from right to left; note also that the *anterior surface* of the distal extremity of the ulna remains facing towards the ceiling in all

positions of the hand, even when the latter lies palm downwards. During this experiment the ulna remains fixed and the hand moves around the axis of the little finger. Now repeat the movement with the flexed forearm free in mid-air. The axis of rotation of the forearm now no longer passes through the little finger, but has moved to the middle finger. The lower extremity of the ulna still faces forward as before; but it moves into slight adduction and abduction, during supination and pronation, in a manner beautifully coordinated. To the basic rotation of the radius around an immobile ulna is superadded a movement of the ulna itself; the actual motion performed by wrist and hand is the resultant of these two movements (Fig. 2.36).

Ulnar movement is produced in two ways. In the usual working position *with elbow flexed* (e.g. turning a screwdriver, a doorknob) abduction and adduction occur between ulna and trochlea. Contraction of the anconeus causes slight abduction and pronation of the ulna, and these movements accompany pronation of the forearm. (Lecomte in 1874 named the anconeus the pronator of the ulna.) Ulnar abduction is opposed by the humeral head of pronator teres. This oblique pull adducts the radius (and hence the ulna). Ulnar movement is illustrated in Figure 2.37.

In the rarer movements around a more laterally placed centre (lateral to the centre of the palm) ulnar movement at the *trochlea* is insufficient. Ulnar abduction and adduction with the elbow flexed are then produced by rotation of the shaft of the humerus, under the action of the short scapular muscles.

The forearm can be pronated and supinated around any finger tip placed on a fixed point. Ulnar movement is least when the little fingertip is fixed, greatest when index finger or thumb is fixed. The axis of rotation at the level of the wrist can thus be made to pass through any point between the styloid processes of radius and ulna; and each styloid process describes a semicircle around that point (Fig. 2.38). Ulnar abduction and adduction are each accompanied by slight extension and then flexion at the elbow in order to bring this about. Thus, during pronation, the first half of the movement is accompanied by abduction and slight extension of the ulna, and the second half by further abduction and slight flexion of the ulna. Likewise during supination the first half of the movement is accompanied by adduction and slight extension of the ulna, and the second half by further adduction and slight flexion of the ulna.

Summarizing, simple pronation and supination about an immobile ulna are rare and unnatural movements. Almost always they are accompanied by

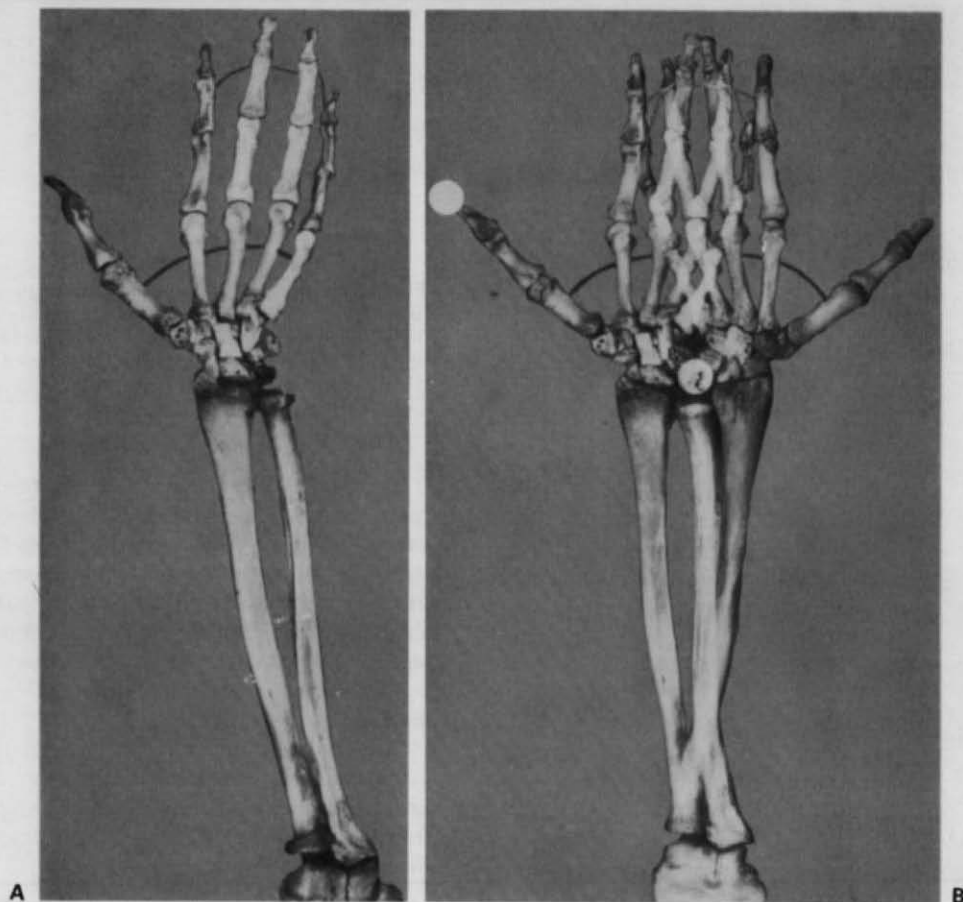


Fig. 2.36 Mechanism of pronation of the left forearm, with a fixed ulna. **A** Articulated bones in supination. **B** Double exposure photograph superimposing on **A** the pronated forearm and hand. The ulna has kept stationary against the marker disc at its lower end, and the axis of pronation has passed through the tip of the middle finger. Note the wide excursion of the tip of the thumb away from its marker disc. The metacarpals and phalanges can be identified where superimposed by identifying the bases of the metacarpals from the thumb side and then tracing distally to the digits. Note that with a fixed ulna the centre of the palm must move, and the grip on a rotating fixture (like a doorknob) is lost. Compare with Figure 2.37.

synergic movements at shoulder and elbow (and rotation of the humerus) to produce simultaneous movement of the ulna.

The muscles producing **pronation** are principally pronator quadratus and pronator teres, with some small assistance from flexor carpi radialis and palmaris longus (and brachioradialis as far as the midprone position). **Supination** is carried out by supinator and biceps, with some assistance from extensor pollicis longus and extensor carpi radialis longus. Note that pronation is essentially a function of the median nerve, while supination depends on the musculocutaneous nerve (biceps) and the radial nerve.

PART 8

POSTERIOR COMPARTMENT OF THE FOREARM

A dozen muscles occupy the extensor compartment. At the upper part are anconeus (superficial) and supinator (deep). From the lateral part of the humerus arise three muscles that pass along the radial side (brachioradialis, and extensors carpi radialis longus and brevis), and three that pass along the posterior surface of the

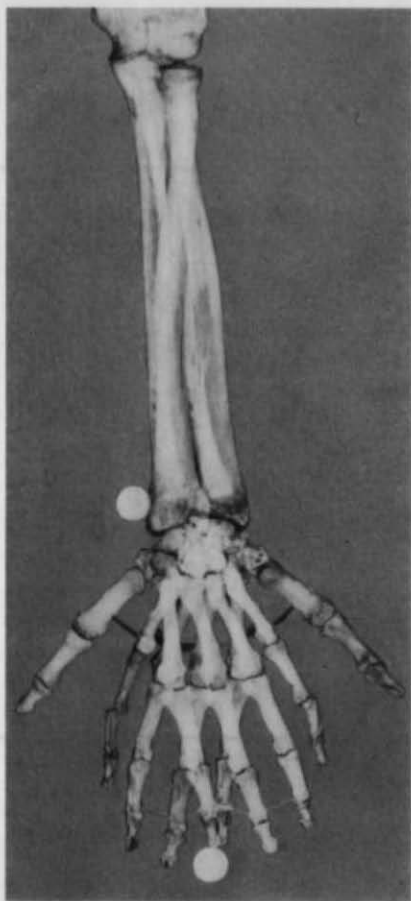


Fig. 2.37 Mechanism of pronation of the left forearm, with ulnar abduction. The hand is articulated as in Figure 2.36 and a double exposure photograph has been made with the hand pronated round the tip of the index finger, marked by a disc. A second (proximal) marker disc shows the edge of the ulna in supination; in pronation the ulna has moved lateral to this and can be seen overlying the shadow of the radius. Thumb excursion is less than in Figure 2.36. To achieve pronation round the tip of the index finger the necessary ulnar abduction is brought about by rotation of the shaft of the humerus (not shown in the picture), with abduction at the shoulder. Note that the centre of the palm has not moved away. It is only by this ulnar movement that a rotating grip can be maintained on fixed objects such as doorknobs, screwdrivers, etc.

forearm (extensors digitorum, digiti minimi and carpi ulnaris). At the lower end of the forearm these two groups are separated by three muscles that emerge from deeply in between them and go to the thumb (abductor pollicis longus and extensors pollicis longus and brevis). Finally, one muscle for the forefinger runs deeply to reach the back of the hand (extensor indicis).

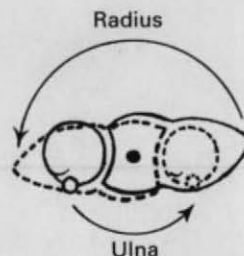


Fig. 2.38 Lower ends of the left radius and ulnar, outlined in supination (solid lines). Pronation around the fixed black dot at the lower end of the radius results in the bones taking up the position of the dotted lines. The curved lines indicate the paths of the radial and ulnar styloid processes as the lower end of the ulna moves into abduction.

The nerve of the extensor compartment is the posterior interosseous nerve, which reaches it by passing around the radius (compare the peroneal nerve in the leg); the artery is the posterior interosseous, which gains the extensor compartment by passing between the two bones (compare the anterior tibial artery in the leg). The artery is small and the blood supply of the posterior compartment is reinforced by the anterior interosseous artery.

The six long muscles that come from the lateral side of the humerus have not enough area available at the lateral epicondyle. Two of them arise high above this, from the lateral supracondylar ridge and the lateral intermuscular septum.

Brachioradialis

Arising from the upper two-thirds of the lateral supracondylar ridge, the muscle passes along the preaxial border of the forearm to a tendon that is inserted at the base of the styloid process of the radius. The muscle forms the lateral border of the cubital fossa (Fig. 2.30); passing down the forearm it overlies the radial nerve and the radial artery as they lie together on supinator, pronator teres tendon, flexor digitorum superficialis and flexor pollicis longus. The lower part of the tendon is covered by abductor pollicis longus and extensor pollicis brevis as they spiral down to the thumb (Fig. 2.39).

Nerve supply. By the radial nerve (C5, 6) from a branch arising above the elbow joint (before the posterior interosseous nerve is given off).

Action. Its action is to flex the elbow joint. It pulls on the radial styloid process, which is thus made the leading point as the forearm flexes; the ulnar side of the forearm passively follows, falling into the position of mid-pronation. This is purely passive. Electromyographic

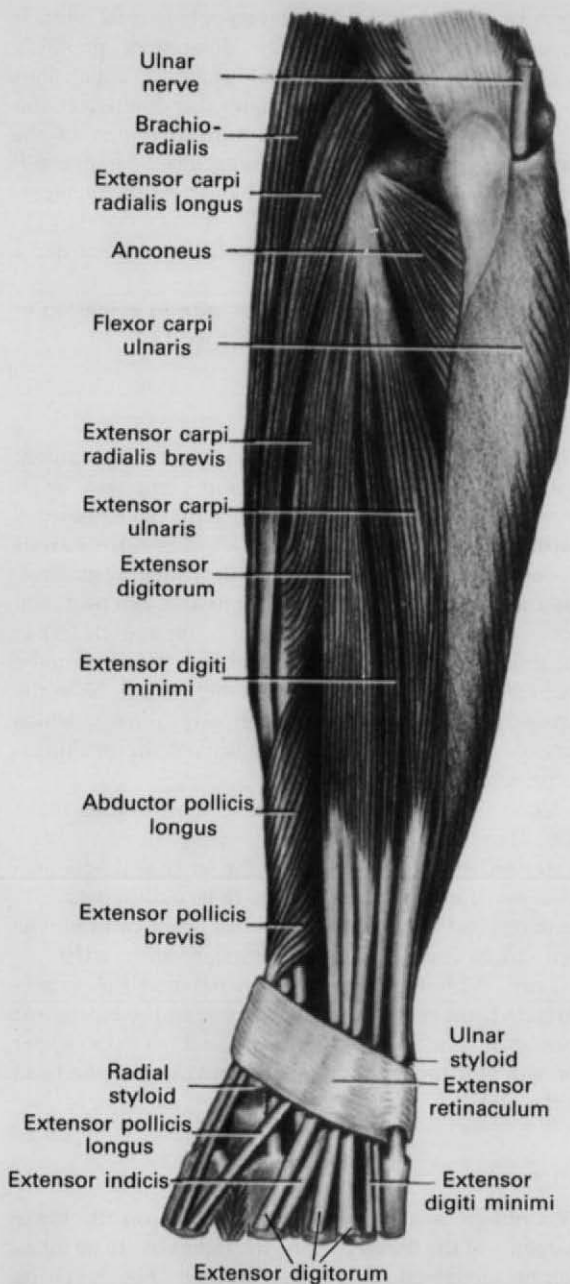


Fig. 2.39 Superficial extensor muscles of the left forearm.

studies indicate that it has some weak pronating action from the fully supine position to midpronation, but it has no supinating action from the fully pronated position. In median nerve paralysis it can be transplanted into flexor pollicis longus to produce thumb flexion.

Test. With the forearm in the midprone position the elbow is flexed against resistance; the muscle can be seen and felt.

Extensor carpi radialis longus

Arising from the lower third of the lateral supracondylar ridge of the humerus the muscle passes down the forearm, behind brachioradialis (Fig. 2.39) and beneath the thumb muscles, to be inserted as a flattened tendon into the base of the second metacarpal.

Nerve supply. By the radial nerve (C6, 7) by a branch arising above the elbow (before the posterior interosseous branch is given off).

Action. It is an extensor and abductor of the wrist and midcarpal joints. It is indispensable to the action of 'making a fist', acting as a synergist during finger flexion; its tendon can be felt and often seen when this is done (p. 119). It assists in flexion of the elbow. In paralysis of forearm flexor muscles it can be transferred into flexor digitorum profundus.

Test. With the forearm pronated the wrist is extended and abducted against resistance. The muscle is palpated below and behind the lateral side of the elbow, and the tendon palpated proximal to the anatomical snuffbox.

Common extensor origin

Examine a humerus. The smooth area on the *front* of the lateral epicondyle is for the attachment of the common extensor origin (Fig. 2.25). From it arise the fused tendons of extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi and extensor carpi ulnaris. All four muscles pass to the posterior surface of the forearm. When the forearm is extended and supinated they spiral around the upper end of the radius; behind this rounded mass of muscle is an elongated pit in which lies the head of the radius. In the *working position* of the forearm (flexed and half pronated), however, these muscles pass straight from the front of the lateral epicondyle into the forearm, as can be seen by an examination of the bones. It is for this reason that the common origin is on the *anterior* surface of the lateral epicondyle. It is to be noted that all four tendons are fused to each other and to the deep fascia near their origin from the humerus.

Extensor carpi radialis brevis

This muscle arises from the common extensor origin on the front of the lateral epicondyle of the humerus, passes down behind and deep to its fellow longus

(Fig. 2.39), and by a flattened tendon is inserted into the base of the third metacarpal. The lower part of the tendon is crossed by the three extensor muscles of the thumb.

Nerve supply. By a branch in the cubital fossa from the posterior interosseous nerve (C6, 7), before the nerve pierces the supinator muscle, though sometimes it arises from the superficial branch of the radial nerve.

Action. As a wrist extensor like its longus companion it is indispensable in 'making a fist' (p. 119). Note that it and the longus are inserted into the same metacarpals as flexor carpi radialis and compare the symmetry of insertion of flexor and extensor carpi ulnaris muscles.

Extensor digitorum

Arising from the common extensor origin the muscle expands into a rounded belly in the middle of the forearm (Fig. 2.39), diverging from the three muscles on the radial side and separated from them by the emergence of the thumb extensors. The four tendons pass under the extensor retinaculum crowded together, overlying the tendon of extensor indicis. On the back of the hand the tendons spread out towards the fingers. Commonly the fourth tendon is fused with that to the ring finger, and reaches the little finger only by a tendinous band that passes across near the metacarpophalangeal joint. Other bands join adjacent tendons in a variable manner. The extensor expansions and their insertions into the phalanges are considered with the hand (p. 118).

Nerve supply. By the posterior interosseous nerve on the back of the forearm (C7, 8).

Action. It is an extensor of the digits and also assists in wrist extension; its action is discussed in detail on page 119.

Test. With the forearm in pronation and the fingers extended, the patient tries to keep the fingers extended at the metacarpophalangeal joints while pressure from the examiner on the proximal phalanges tries to flex these joints.

Extensor digiti minimi

Arising in common with the extensor digitorum the belly of the muscle separates after some distance (Fig. 2.39) and then becomes tendinous. Passing beneath the extensor retinaculum on the dorsal aspect of the radioulnar joint the tendon usually splits into two which lie side by side on the fifth metacarpal bone as they pass to the little finger (Fig. 2.44). The tendon of extensor digitorum to the little finger commonly joins

them by a band near the metacarpophalangeal joint. It becomes an expansion on the dorsum of the little finger, behaving as the other extensor expansions (p. 118). Do not be confused by the double tendon of extensor digiti minimi and think that one of the tendons belongs to extensor digitorum — it doesn't! The digitorum connexion is the band near the metacarpophalangeal joint (Fig. 2.44).

Nerve supply. By the posterior interosseous nerve (C7, 8).

Action. It assists extensor digitorum in extension of the little finger and wrist joint; see page 119.

Extensor carpi ulnaris

There is an origin from the common extensor tendon; as the muscle slopes downwards it is completed by an aponeurotic sheet of origin from the subcutaneous border of the ulna (Fig. 2.39). This aponeurosis arises in common with that of flexor carpi ulnaris, the two passing in opposite directions into the extensor and flexor compartments. The tendon of the muscle lies in the groove beside the ulnar styloid as it passes on to be inserted into the base of the fifth metacarpal. Note the symmetry of insertion with flexor carpi ulnaris, which acts on the fifth metacarpal by way of the pisometacarpal ligament.

Nerve supply. By the posterior interosseous nerve (C6, 7) in the forearm.

Action. It is an extensor of the wrist and acts as a synergist during finger flexion. It is indispensable in 'making a fist' (p. 119). Acting with flexor carpi ulnaris it produces ulnar deviation (adduction) at the wrist.

Test. With the forearm pronated and the fingers extended, the wrist is extended and adducted against resistance. The muscle can be seen and felt in the upper forearm and the tendon palpated proximal to the head of the ulna.

Anconeus

This muscle arises from a smooth facet on the lower extremity of the lateral epicondyle. It fans out to its insertion on the lateral side of the olecranon (Fig. 2.41). Its lateral fibres are vertical, in the axis of the forearm, but its upper fibres are horizontal, passing transversely across the forearm.

Nerve supply. By the radial nerve (C7, 8) by a branch that leaves the trunk in the radial groove and passes through triceps with the nerve to its medial head.

Action. The muscle produces the small amount of extension and abduction of the ulna that occurs during pronation (p. 96).

Supinator

This muscle consists of two parts with different origins and passing in different directions (Fig. 2.40). The posterior interosseous nerve passes between these two parts as it leaves the cubital fossa to enter the back of the forearm.

The *deep part* of the supinator consists of fibres that arise from the supinator crest and fossa of the ulna and wrap *horizontally* around the radius to be inserted into the area between the anterior and posterior oblique lines. The *superficial part* arises from the distal border of the lateral epicondyle (just in front of anconeus), from the radial collateral (lateral) ligament of the elbow joint and from behind the supinator crest above abductor pollicis longus (Fig. 2.41). The fibres slope *downwards* to overlie the horizontal deep fibres and reach the radius just above the anterior oblique line.

Nerve supply. A branch to both parts of the supinator (C5, 6) leaves the posterior interosseous nerve in the cubital fossa before the nerve enters the muscle.

Action. Note that biceps is the *powerful* supinator of the forearm; supinator itself is to be regarded rather as a

muscle that fixes the forearm in supination. Only when the elbow is completely extended is the supinator the prime mover for the action of supination, which is much weaker in this position. The muscle is too deep to be seen or palpated.

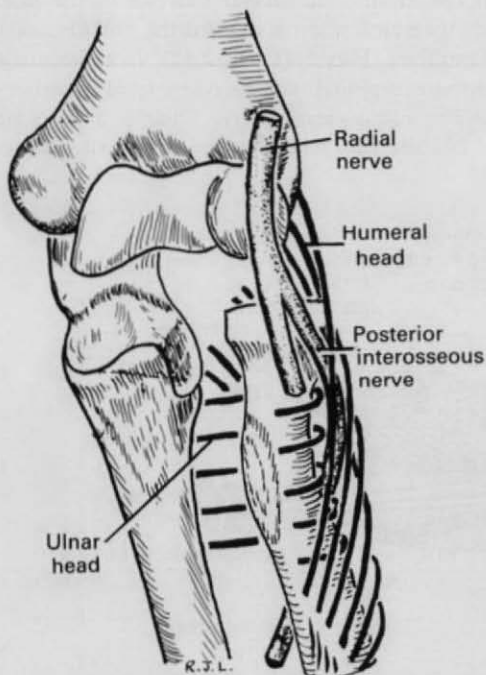


Fig. 2.40 Layers of the left supinator muscle. The posterior interosseous nerve passes between the two layers.

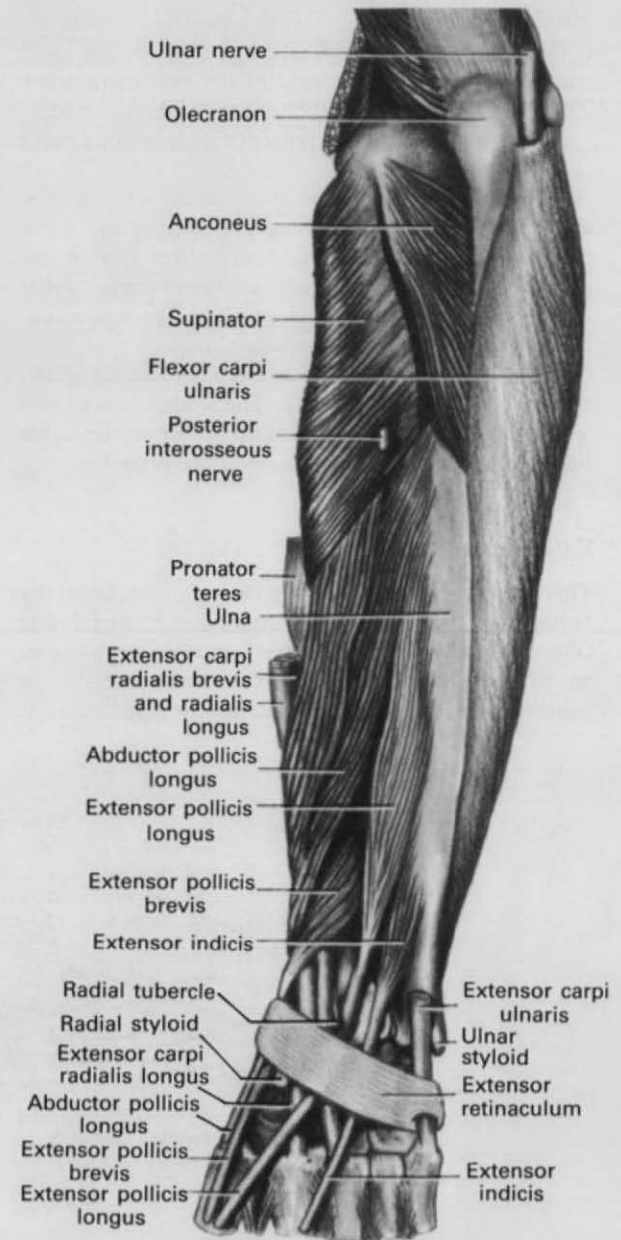


Fig. 2.41 Deep extensor muscles of the left forearm. Compare with Figure 2.64.

Abductor pollicis longus

This arises from an oblique area on both bones of the forearm and the intervening interosseous membrane. Its radial origin lies immediately distal to the posterior oblique line. The ulnar origin is more proximal (Fig. 2.64). The muscle has separate superficial and deep parts and gives rise to a variable number of tendons. The deep part has a tendon that is mainly inserted into the trapezium, with a slip joining abductor pollicis brevis. The superficial part ends in one or more tendons attached to the base of the first metacarpal. There is a bursa between the tendons of the two parts.

Nerve supply. By the posterior interosseous nerve (C7, 8).

Action. Its name indicates that it abducts the thumb, and it can assist in abducting and flexing the wrist, producing a 'trick' flexion when other flexors are paralysed. The disposition of the tendons suggests that the deep part of the muscle stabilizes the trapezium, upon which the first metacarpal can move.

Test. The thumb is abducted at the metacarpophalangeal joint against resistance. The tendon is seen and felt at the radial side of the snuffbox and on the radial side of the adjacent extensor pollicis brevis tendon.

Extensor pollicis brevis

This arises below abductor pollicis longus from the radius and the adjacent interosseous membrane (Fig. 2.41). It spirals from the depths of the forearm around the radial extensors and brachioradialis, in contact with abductor pollicis longus, whose tendon it

somewhat overlies on the radial border of the snuffbox. Its slender tendon lies with the tendon of abductor pollicis longus at the radial border of the snuffbox and then passes along the dorsal surface of the first metacarpal, and is inserted into the base of the proximal phalanx.

Nerve supply. By the posterior interosseous nerve (C7, 8).

Action. It extends the carpometacarpal and metacarpophalangeal joints of the thumb (Fig. 2.42). It prevents flexion of the metacarpophalangeal joint when flexor pollicis longus is flexing the terminal phalanx, as in pinching index and thumb pads together (e.g. threading a needle).

Test. The thumb is extended at the metacarpophalangeal joint against resistance. The tendon is seen and felt at the radial side of the snuffbox and on the ulnar side of the adjacent abductor pollicis longus tendon.

Extensor pollicis longus

This arises from the ulna just distal to abductor pollicis longus (Fig. 2.41). Thus it extends higher into the forearm than extensor pollicis brevis. It extends more distally also into the thumb, being inserted into the base of the distal phalanx. Its long tendon changes direction as it hooks around the dorsal tubercle of the radius (Lister's tubercle), whence it forms the ulnar boundary of the snuffbox (Figs 2.41 and 2.42). In this situation the tendon is supplied with blood by local branches of the anterior interosseous artery. Their occlusion after Colles' fracture may lead to necrosis and spontaneous

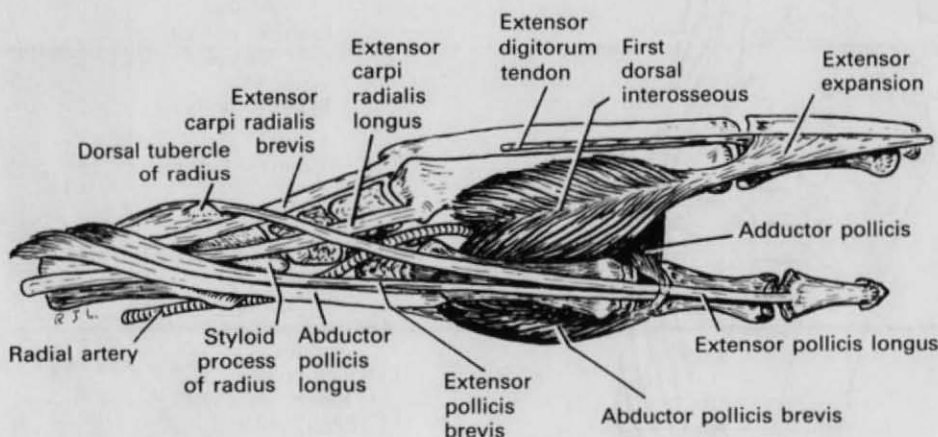


Fig. 2.42 Left anatomical snuffbox. It lies between the extensor tendons of the thumb. In its bony floor are the radial styloid, scaphoid, trapezium and base of the first metacarpal (compare with Fig. 2.67). The floor is crossed by the radial artery.

rupture of the tendon — hammer thumb. Such a rupture is not due to wearing through of the tendon as it grates over the fragments.

There is no extensor expansion on the thumb; the tendon of extensor pollicis longus is stabilized on the dorsum of the thumb by receiving expansions from abductor pollicis brevis and adductor pollicis.

Nerve supply. By the posterior interosseous nerve (C7, 8).

Action. It extends the terminal phalanx of the thumb, and draws the thumb back from the opposed position (Figs 2.41 and 2.42), assisting in extension and abduction of the wrist.

Test. The thumb is extended at the interphalangeal joint against resistance. The tendon is seen and felt on the ulnar side of the snuffbox.

Extensor indicis

This small muscle arises from the ulna just distal to the former muscle (Fig. 2.41). Its tendon remains deep and passes across the lower end of the radius covered by the bunched-up tendons of extensor digitorum with which it shares a common synovial sheath. From here it passes over the dorsal surface of the metacarpal bone of the index finger lying to the ulnar side of the digitorum tendon (Fig. 2.44). It joins the dorsal expansion of the index finger. Thus, like the dorsal surface of the little finger, the index finger has two tendons passing to it but they belong to different muscles: the indicis tendon is on the ulnar side of the digitorum tendon.

Nerve supply. By the posterior interosseous nerve (C7, 8).

Action. It extends the index finger, as in pointing as well as assisting extensor digitorum in this movement.

Anatomical snuffbox

If the thumb is fully extended the extensor tendons are drawn up, and a concavity appears between them on the radial side of the wrist. The 'snuffbox' lies between the extensor pollicis longus tendon on the ulnar side and the tendons of extensor pollicis brevis and abductor pollicis longus on the radial side (Fig. 2.42). The cutaneous branches of the radial nerve cross these tendons, and they can be rolled on the tight tendon of extensor pollicis longus. The cephalic vein begins in the snuffbox, from the radial side of the dorsal venous network. The radial artery, deep to all three tendons, lies in the floor. Bony points readily palpable in the snuffbox are the radial styloid proximally, and the base of the thumb metacarpal distally; between the two the scaphoid and trapezium can be felt.

Posterior interosseous nerve

After passing through the supinator muscle between its two layers the nerve appears in the extensor compartment of the forearm (Fig. 2.41) and passes downwards over the abductor pollicis longus origin. It now dips deeply to reach the interosseous membrane on which it passes between the muscles as far as the wrist joint. Here it ends in a small nodule from which branches supply the wrist joint and intercarpal ligaments. The nerve supplies the muscles which arise from the common extensor origin and the deep muscles of the extensor compartment. It is sensory to the interosseous membrane and periosteum of the radius and ulna, and to the dorsal periosteum and ligaments of the carpal bones. It has no cutaneous branch.

Posterior interosseous artery

This vessel gains the extensor compartment by passing between the bones of the forearm above the interosseous membrane and below the oblique cord. It accompanies the posterior interosseous nerve and supplies the deep muscles of the extensor compartment. At the lower border of extensor indicis this small vessel is generally exhausted. Distal to this level the arterial supply of the extensor compartment is furnished by the *anterior* interosseous artery, which pierces the interosseous membrane just above the upper border of pronator quadratus (Fig. 2.33). The anterior interosseous artery then passes distally to end on the back of the wrist in the dorsal carpal anastomosis.

Extensor retinaculum

The **extensor retinaculum** is a ribbon-like band, less than 2.5 cm wide, which lies *obliquely* across the extensor surface of the wrist joint (Fig. 2.44). Its proximal attachment is to the radius at the anterolateral border above the styloid process, at the lateral border of pronator quadratus. It is *not* attached to the ulna; its upper border passes by the styloid process of the ulna. It is attached to the pisiform and triquetral bones. It is a thickening in the deep fascia of the forearm. Immediately proximal to it the deep fascia is attached to the styloid process of the ulna but the oblique fibres which pass from here to the radial side are not attached to the radius, being held away from the bone by the extensor muscles of the thumb.

If the extensor retinaculum were attached to both bones of the forearm it would be over 30% longer in pronation than in supination, as is shown by measure-

ment on the bones. Such elongation is obviously not possible and, in fact, the retinaculum, attached to the radius and carpus and free from the ulna, maintains a constant tension throughout the whole range of pronation and supination, while the radius and carpus move together around the lower end of the ulna. Thus the retinaculum holds down the extensor tendons, like a wrist strap, in all positions of the forearm bones.

From the deep surface of the extensor retinaculum fibrous septa pass to the bones of the forearm, dividing the extensor tunnel into six compartments. The most lateral compartment lies over the lateral surface of the radius at its distal extremity, and through it pass the tendons of abductor pollicis longus and extensor pollicis brevis, each usually lying in a *separate synovial sheath*. The next compartment extends as far as the dorsal tubercle, and conveys the tendons of the radial extensors of the wrist (longus and brevis) each lying in a separate synovial sheath (see Fig. 2.64 for these and other grooves on the radius and ulna). The groove on the ulnar side of the radial tubercle lodges the tendon of extensor pollicis longus, which lies within its own compartment invested with a synovial sheath. Between this groove and the ulnar border of the radius is a shallow depression in which all four tendons of extensor digitorum lie, crowded together over the tendon of extensor indicis. All five tendons in this compartment are invested with a common synovial sheath. The next compartment lies over the radioulnar joint and transmits the double tendon of extensor minimi digiti in a synovial sheath. Lastly, the groove near the base of the ulnar styloid transmits the tendon of extensor carpi ulnaris (in its synovial sheath) which then passes into its own compartment on the dorsal surface of the carpus to reach the fifth metacarpal bone.

PART 9

WRIST AND HAND

The **hand** includes the wrist whose skeleton is the carpus or carpal bones, but the word 'wrist' is often used to include the lower ends of the radius and ulna. The back of the hand is the dorsum or dorsal surface (extensor surface), while the palm or palmar surface is the flexor surface.

The hand of man differs from the manus of other creatures in being a grasping mechanism combining great strength with finely controlled accuracy and at the same time serving as the chief tactile organ. Apart from the free mobility of the thumb its component parts

differ little from those of the foot; indeed their similarity is very striking (p. 237). The great difference lies in the richness of the cortical connexions, both sensory and motor, in the case of the hand. Over half of the fibres of the corticospinal tract are concerned with upper limb movements, which are usually directed to getting the hand into the required position and putting it to work. The anatomical structures to be studied in the hand differ not at all between the unskilled labourer, the skilled craftsman and the artist. They comprise the same four layers as in the foot (p. 197). Beneath the skin of the palm lies the strong palmar aponeurosis. Next lie the short muscles of the thumb and little finger and the long flexor tendons. More deeply is the adductor muscle of the thumb, then the metacarpal bones with their interosseous muscles. The long flexor tendons supply the power of the grip; the 'small muscles of the hand' are responsible for adjusting the position and carrying out the finer skilled movements of the digits. In contrast to the palm, the dorsum of the hand has little but skin and sinew covering the bones.

DORSUM OF THE HAND

The skin of the dorsum is loose and can be picked up from the underlying tendons and moved freely over them — except in a very podgy hand.

The **cutaneous innervation** of the dorsum is by the terminal branches of the radial nerve and the dorsal branch of the ulnar nerve (Fig. 2.43). They share the hand and its digits $3\frac{1}{2}$ to $1\frac{1}{2}$, though a distribution $2\frac{1}{2}$ to $2\frac{1}{2}$ is not uncommon. The ends of the nerves pass round to the dorsum of each digit, where they stop short of the nail beds (which are supplied $3\frac{1}{2}$ to $1\frac{1}{2}$ by the nerves of the flexor skin, the median and the superficial branch of the ulnar nerves).

Large veins forming the **dorsal venous network** (or arch) lie beneath the skin; they drain from the palm, so that the pressure of gripping does not impede venous return. The network lies superficial to the extensor tendons, proximal to the metacarpal heads, and drains on the radial side into the cephalic vein and on the ulnar side into the basilic vein.

Beyond the extensor retinaculum the extensors of the wrist (two radial and one ulnar) are inserted into the proximal part of the hand, at the bases of their respective metacarpal bones. Lying more superficially, the extensor tendons of the fingers fan out over the dorsum of the hand, attached to the deep fascia of this region and interconnected near the metacarpal heads by a variable arrangement of oblique fibrous bands (inter-tendinous connexions) (Fig. 2.44). The deep fascia and the subjacent extensor tendons roof in a subfascial

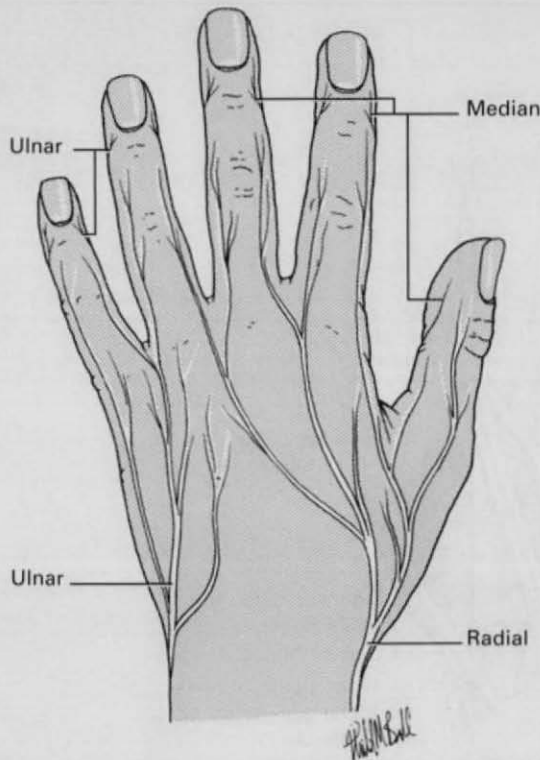


Fig. 2.43 Cutaneous innervation of the dorsum of the left hand.

space that extends across the whole width of the hand. Passing to the index finger are the tendons of extensor digitorum and extensor indicis lying together, while the tendon of extensor digiti minimi to the little finger is usually split longitudinally into two (Fig. 2.44). The two tendons over the second metacarpal bone thus belong to two separate muscles, while the two tendons usually seen over the fifth metacarpal belong to only one muscle. The tendon of extensor digitorum to the little finger lies over the metacarpal bone of the *ring* finger.

The **posterior carpal arch** is an arterial anastomosis between the radial, ulnar and *anterior* interosseous arteries. It lies on the back of the carpus and sends *dorsal metacarpal arteries* distally in the intermetacarpal spaces, deep to the long tendons. These split at the webs to supply the dorsal aspects of adjacent fingers. They communicate through the interosseous spaces with the palmar metacarpal branches of the deep palmar arch. Companion veins bring blood from the palm into the dorsal venous network mentioned above.

WRIST JOINT

This is a synovial joint whose bony surfaces are formed

proximally by the distal surface of the radius and the attached articular disc of the distal radioulnar joint (p. 95), and distally by the scaphoid, lunate and triquetral bones. The triangular fibrocartilage, which holds the lower ends of the radius and ulna together, separates the wrist (radiocarpal) joint from the distal radioulnar joint. It does not transmit thrust from the hand. Examine the lower end of the radius. The triangular facet whose apex is the styloid process is for articulation with the scaphoid. The rectangular area next to it is for the lunate. The triquetral is adjacent to the disc and the ulnar collateral ligament; only in extreme degrees of adduction may the triquetral make contact with the radius. It is a common fallacy to think that 'the triquetral only takes part in the joint in extreme adduction'. The fallacy is in thinking that 'taking part in the joint' is the same as 'articulating with the radius'; the triquetral is *always* part of the joint. A simple **capsule** surrounds the joint and is thickened on the radial and ulnar sides by **collateral ligaments**, and in general is much thicker in front than behind. Strong ligaments run transversely from the lower end of the radius to the lunate, forming the palmar radiocarpal ligament.

Nerve supply. By twigs from the posterior interosseous (radial) and anterior interosseous (median) nerves.

Movements at the joint are flexion and extension, adduction (ulnar deviation) and abduction (radial deviation). These four movements occurring in sequence produce circumduction. Some of the movement of flexion and extension is always accompanied by similar movement at the midcarpal joint (p. 120). Of the total range of flexion (about 80°), a greater proportion occurs at the midcarpal joint; in extension (60°), there is a greater proportion at the wrist joint itself. The four movements are carried out by combinations of muscle groups. Thus **flexion** is produced by flexor carpi radialis and flexor carpi ulnaris as prime movers, by palmaris longus and the flexors of fingers and thumb and abductor pollicis longus. **Extension** is produced by the radial extensors (longus and brevis) and the ulnar extensor as prime movers assisted on occasion by the extensors of fingers and thumb. **Abduction** (limited to about 15° because of the projection of the radial styloid) is carried out by abductor pollicis longus and, when the wrist is displaced from the midline, by flexor carpi radialis and the two radial extensors acting together. Similarly **adduction** (60°) is brought about by simultaneous contraction of flexor and extensor carpi ulnaris. In the rest position the axis of the metacarpus (third metacarpal) is not in line with the axis of the forearm. With the supinated forearm by the side the axis of the hand is parallel with the humerus,

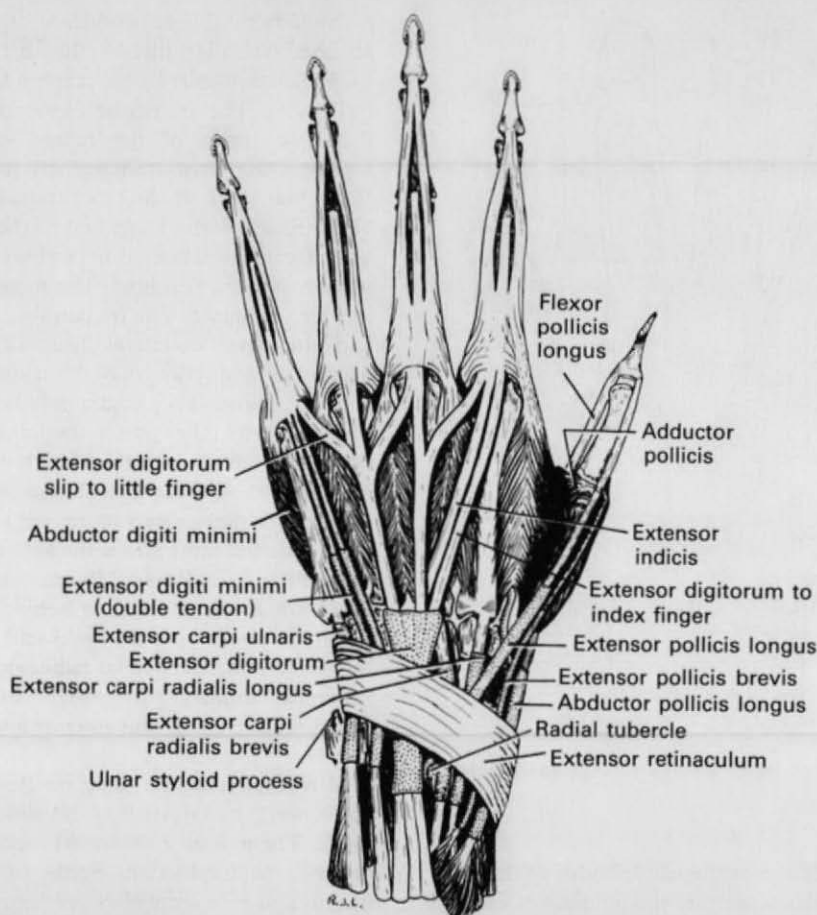


Fig. 2.44 Left extensor retinaculum and synovial sheaths of the extensor tendons. Note the obliquity of the retinaculum compared with the transversely-placed flexor retinaculum in Figure 2.31.

thus compensating for the carrying angle at the elbow. Lateral movements of the wrist are symmetrical about this axis, but they are, ipso facto, not symmetrical about the axis of the forearm, from which the metacarpus can be brought further into ulnar adduction than into radial abduction. In the former movement there is some gliding of the carpal bones across the lower end of the radius but in the latter the carpal bones, rather, rotate each about its own axis.

It is worth noting that the most usual movement of the wrist is one of extension combined with radial abduction, and of flexion combined with ulnar adduction. Hammering in a nail illustrates this movement, and exactly similar movements of the wrist, in the working position of the forearm, occur in a host of

everyday acts like eating and drinking, washing and dressing, writing, etc. Indeed, pure flexion-extension and abduction-adduction are unusual movements. Since extension-abduction is an antigravity movement in the normal working position, this may explain the presence of two radial extensors where one serves on the ulnar side, and there is only one flexor each for radial and ulnar sides.

Surgical approach. The usual approach is on the dorsal surface, on the ulnar side of the tendon of extensor pollicis longus, the tendons of extensor digitorum and extensor indicis being displaced medially to expose the capsule. There are no major vessels or nerves in this region. Needle puncture of the joint is carried out between the tendons of extensor pollicis

longus and extensor digitorum; the styloid process of the radius is palpated in the snuffbox to indicate the level of the joint line.

PALM OF THE HAND

The **skin** of the palm is characterized by flexure creases (the 'lines' of the palm) and the papillary ridges, or 'fingerprints', which occupy the whole of the flexor surface. Perhaps the latter serve to improve the grip; certainly they increase the surface area. Sweat glands abound. The little **palmaris brevis** muscle is attached to the dermis; it is part of the panniculus carnosus (p. 3). It lies across the base of the hypothenar eminence and is the only muscle supplied by the superficial branch of the ulnar nerve. It may improve the grip by steadying the skin on the ulnar side of the palm.

Elsewhere the skin is steadied by its firm attachment to the palmar aponeurosis. Fibrous bands connect the two and divide the subcutaneous fat into myriads of small loculi, forming a 'water-cushion' capable of withstanding considerable pressure. When cut the tension causes some bulging of these fatty loculi.

The *cutaneous innervation* of the palm is mainly by the superficial and palmar branches of the ulnar nerve (p. 114) and by the median nerve and its palmar branch (pp. 111 and 94), probably supplemented proximally by the very ends of the medial and lateral cutaneous nerves of the forearm (p. 94) and over the base of the thenar eminence by the radial nerve (p. 94).

Palmar aponeurosis

This strongly unyielding ligament is phylogenetically the degenerated tendon of palmaris longus (p. 89). It extends, in continuity with the tendon, from the distal border of the flexor retinaculum, whence it fans out in a thick sheet towards the bases of the fingers. It divides into four slips, one for each finger. Each slip gives off superficial fibres that insert into the skin in the region of the crease at the base of the finger, while the main part divides into two bands over the proximal end of the fibrous flexor sheath; they are inserted into the deep transverse ligament of the palm, and into the bases of the proximal phalanges and the fibrous flexor sheaths (Fig. 2.45). Some strands from the aponeurosis pass up on each side of the finger. When the fingers are forcibly extended the soft tissues of the palm can be seen bulging in the three intervals between the four slips, just proximal to the interdigital webs.

Over the hypothenar muscles the deep fascia is much thinner than the palmar aponeurosis and it is thinnest

of all over the thenar muscles. This is in keeping with the increased mobility of the metacarpal bone of the thumb (note that the plantar aponeurosis over the big toe muscles is thick; the first metatarsal has very little freedom of movement). The function of the palmar aponeurosis is purely mechanical. It gives firm attachment to the skin of the palm to improve the grip, and it protects the underlying tendons. Contraction of the aponeurosis and its digital slips in Dupuytren's contraction results in a fixed flexion of the fingers concerned (usually the ring and little fingers).

Flexor retinaculum

The **flexor retinaculum** is a strong band that is attached on the radial side to the tubercle of the scaphoid and ridge of the trapezium and on the ulnar side to the pisiform and hook of the hamate. Note that these four bony points are all palpable in the living hand and that the pisiform is the only carpal bone to give attachments to both the flexor and extensor retinacula. There is a further attachment on the radial side, where a deep partition bridges the groove on the trapezium. The fibro-osseous tunnel so formed transmits the tendon of flexor carpi radialis and its synovial sheath (Fig. 2.46).

The muscles of the thenar and hypothenar eminences arise from the retinaculum and several structures pass across it. The tendon of palmaris longus is fused to the midline of the retinaculum as it passes distally to expand into the palmar aponeurosis. The ulnar nerve lies on the retinaculum alongside the pisiform bone, with the ulnar artery on its radial side (Fig. 2.29). Both are bridged over by a slender band of tissue officially called the superficial part of the retinaculum, forming a small canal (of Guyon) that may occasionally cause compression of the nerve. The nerve divides into a superficial (cutaneous) and a deep (muscular) branch at the distal border of the retinaculum; the deep branch is accompanied by a small deep branch of the artery. Near the ulnar side of the palmaris longus tendon the small palmar branch of the ulnar nerve enters the palm, while on the radial side of the tendon the palmar branch of the median nerve and the superficial palmar branch of the radial artery cross the retinaculum. The radial side of the retinaculum is pierced proximally by the tendon of flexor carpi radialis over the scaphoid; further distally the tendon lies deeply in its fibro-osseous tunnel on the trapezium.

Carpal tunnel

The carpus is deeply concave on its flexor surface. This

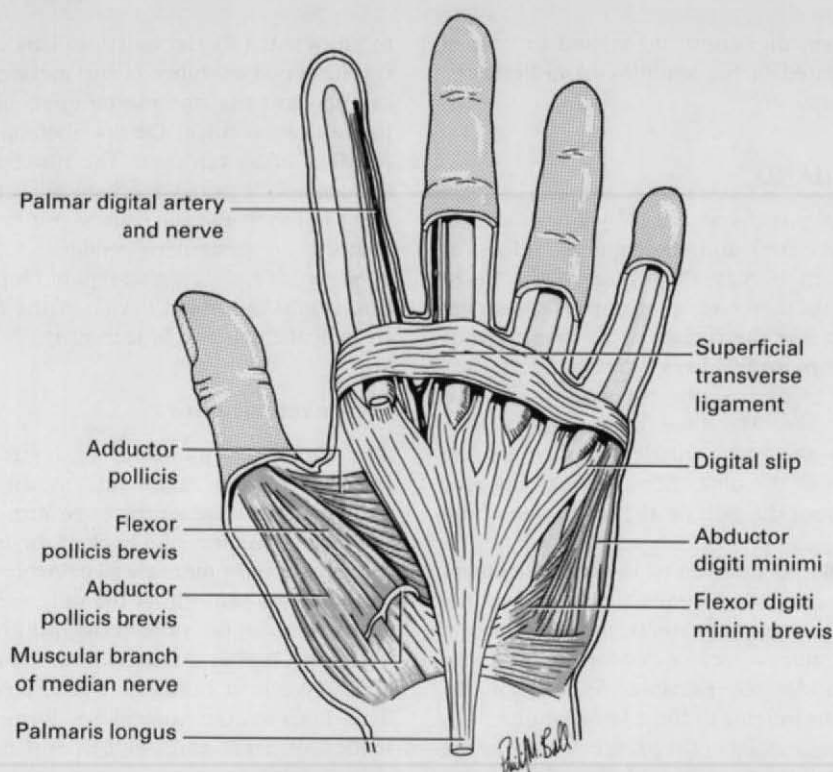


Fig. 2.45 Left palmar aponeurosis and superficial transverse ligament. The central part of the aponeurosis is shown splitting into the four digital slips, each of which splits into two to fuse with the sides of the metacarpophalangeal joint and fibrous flexor sheath of its own finger. Between each main digital slip the common palmar digital artery divides into the palmar digital arteries (as shown at the base of the first finger cleft), but the corresponding common palmar digital nerve has divided more proximally.

bony gutter is converted into 'the carpal tunnel' by the flexor retinaculum (Fig. 2.46). The long flexors of the fingers and thumb run through the tunnel. The four tendons of the superficial flexor are separate from each other and pass through in two rows, middle and ring finger tendons lying in front of index and little finger tendons. The tendons of flexor digitorum profundus, on the other hand, lie all on the same plane deep on the carpal bones; but here only the tendon to the index finger is yet separated, the other three being adherent to each other as they run in the tunnel, and not splitting free until they gain the palm (Fig. 2.31). All eight tendons of the superficial and deep flexors share a common synovial sheath. It does not invest them completely, but is reflected from their radial sides, where arteries of supply gain access to the tendons. It is as though the tendons had been invaginated into the sheath from the radial side (Fig. 2.46). The tendon of flexor pollicis longus lies in its own synovial sheath as it passes through the fibro-osseous tunnel beside the

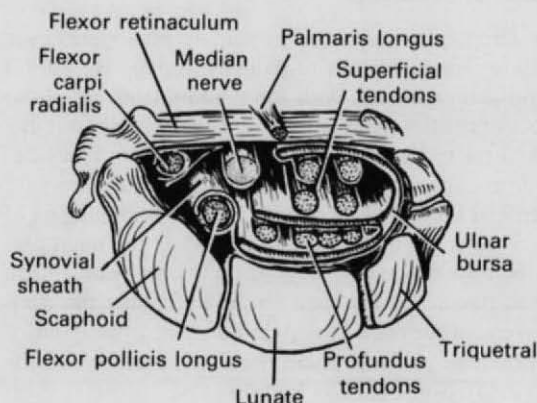


Fig. 2.46 Left carpal tunnel, looking distally towards the palm. For clarity the tendons and median nerve have been separated from each other; in life they are closely packed in the tunnel. The synovial sheath that forms the ulnar bursa is open towards the radial side for the access of blood vessels to the tendons.

trapezium. The median nerve passes beneath the flexor retinaculum on the lateral side of flexor digitorum superficialis (middle finger tendon), between it and flexor carpi radialis. For the carpal tunnel syndrome, see page 111.

Thenar eminence

The thenar eminence is made up of the three short thumb muscles whose origin is essentially from the flexor retinaculum (Fig. 2.47). The most radial of these is **abductor pollicis brevis**. It arises from the flexor retinaculum and the tubercle of the scaphoid and is inserted into the radial side of the base of the proximal phalanx and the tendon of extensor pollicis longus (Fig. 2.42).

Flexor pollicis brevis lies to the ulnar side of the abductor. It arises from the flexor retinaculum and adjacent trapezium and is inserted into the radial sesamoid of the thumb and so to the radial border of

the proximal phalanx. Irregularities of origin are fairly common and have been given many names. The least confusing descriptive nomenclature is to call any fibres that are inserted into the radial sesamoid flexor pollicis brevis, no matter what their origin; fibres inserted into the ulnar sesamoid should not be named flexor pollicis brevis, but considered part of either adductor pollicis or the first palmar interosseous.

Opponens pollicis lies deep to the former two muscles (Fig. 2.50). It arises from the flexor retinaculum and the adjacent trapezium and is inserted into the whole of the radial border of the metacarpal bone of the thumb (Fig. 2.50).

Nerve supplies. All three muscles are supplied by the muscular (recurrent) branch of the median nerve (mainly T1 but with some component from C8), but it is necessary to qualify this simple statement. The nerve supply of flexor pollicis brevis is subject to more variation than that of any other muscle in the body. It may be from the muscular branch of the median nerve or the

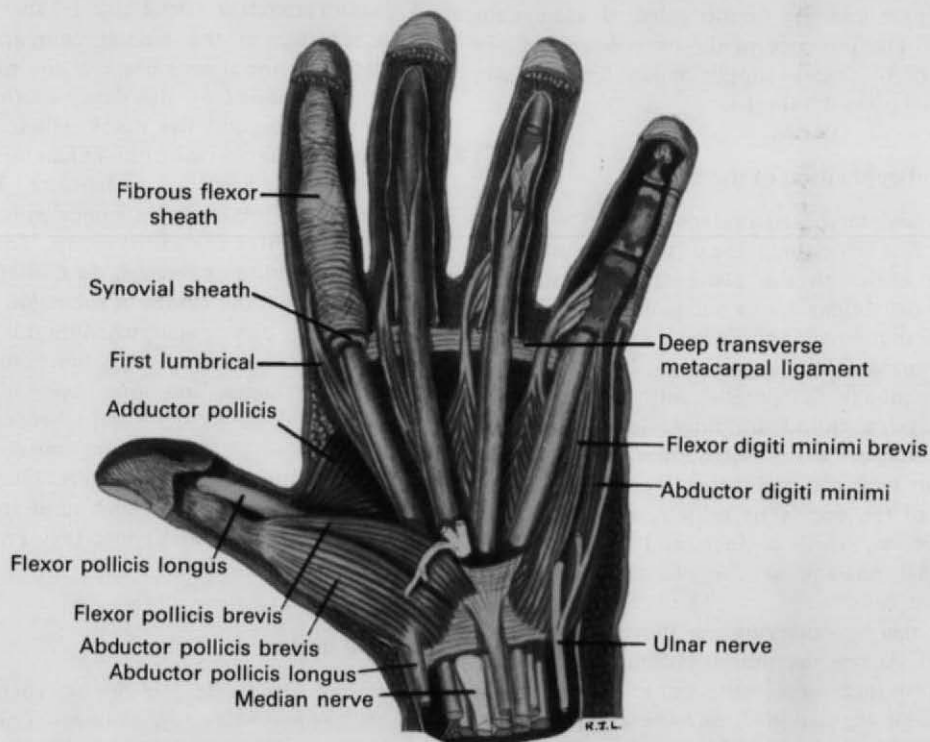


Fig. 2.47 Muscles and tendons of the left palm. The index finger shows the fibrous flexor sheath with the synovial sheath bulging proximally. The middle finger shows the long tendons exposed by incision of the flexor sheath. In the ring finger the profundus tendon has been removed, and in the little finger all is removed down to the phalanges. The first and second lumbricals are unicapital, the third and fourth bicipital. The median nerve passes beneath the flexor retinaculum and immediately gives off the muscular (recurrent) branch to the thenar muscles.

deep branch of the ulnar nerve, or it may have a double supply from both nerves. The opponens usually has a double supply, and there may be other anomalies including even (though very rarely) the supply of all three by the ulnar nerve alone. All these possibilities must be kept in mind when testing for nerve injuries (p. 127).

Actions. The actions of the three muscles are indicated by their names. The abductor abducts the thumb (moving it in a plane at right angles to the palm), and it also abducts the proximal phalanx at the metacarpophalangeal joint and slightly rotates the phalanx. It is thus an indispensable aid in opposition of the thumb (see below). By the slip to the tendon of extensor pollicis longus it can assist in extension of the thumb. The flexor flexes the proximal phalanx and draws the thumb across the palm, and the opponens opposes the metacarpal of the thumb (see below).

Tests. For abductor pollicis brevis the thumb is abducted against resistance, at right angles to the palm; the muscle can be seen and felt. For opponens the thumb is brought against resistance towards the base of the little finger and the thumb palpated against the metacarpal. The presence of the long flexor and the variability of the nerve supply makes testing flexor pollicis brevis of doubtful value.

Flexion and opposition of the thumb

Hold the hand in the neutral position of complete relaxation. Note that the plane of the four fingernails is at right angles to the plane of the thumbnail. Flexion of the thumb across the palm maintains the plane of the thumbnail; opposition, on the other hand, rotates the metacarpal and phalanges in such manner that the thumbnail lies parallel with the nail of the opposed finger, as thumb and finger lie in contact pad to pad. Rotation of the metacarpal at its saddle-shaped joint with the trapezium is produced by the skew pull of the opponens muscle, assisted by the abductor brevis, which abducts and slightly rotates the proximal phalanx at the metacarpophalangeal joint.

Confirm this by observing the movement in your own thumb. At rest the thumb phalanges are in line with their own metacarpal bone, but in full opposition there is notable angulation at the metacarpophalangeal joint. This abduction carries the pad of the thumb still farther towards the ulnar side of the hand. The slight rotation of the proximal phalanx produced at the same time by abductor pollicis brevis aids in bringing the pad of the thumb opposite to the pad of the opposed finger.

Hypothenar eminence

In name the muscles that form the hypothenar eminence on the ulnar side of the palm are similar to the three thenar muscles. **Abductor digiti minimi** is the most ulnar of the group (Fig. 2.47); it arises from the pisiform bone and flexor retinaculum and is inserted into the ulnar side of the base of the proximal phalanx and into the extensor expansion. A sesamoid bone is common in its tendon. **Flexor digiti minimi brevis** (Fig. 2.47) arises from the flexor retinaculum and is inserted into the base of the proximal phalanx. **Opponens digiti minimi** (Fig. 2.50) also arises from the flexor retinaculum and the hook of the hamate and is inserted into the ulnar border of the fifth metacarpal bone.

Nerve supplies. By the deep branch of the ulnar nerve (C8, T1).

Actions. All three hypothenar muscles help to cup the palm and assist in the grip on a large object.

Superficial palmar arch

This is an arterial arcade (Fig. 2.48) that lies superficial to everything in the palmar compartment, i.e. in contact with the deep surface of the palmar aponeurosis. It is formed by the direct continuation of the ulnar artery beyond the flexor retinaculum but it is badly named, for in two-thirds of hands it has a hockey-stick shape and is not a complete arch (Fig. 2.48). If it is complete it becomes continuous with the superficial palmar branch of the radial artery. This branch may pass superficial to or through the thenar muscles. The arch lies across the centre of the palm, level with the distal border of the outstretched thumb web. From its convexity a *palmar digital artery* passes to the ulnar side of the little finger, and three *common palmar digital arteries* run distally to the webs between the fingers where each vessel divides into *proper palmar digital arteries* that supply adjacent fingers. The thumb side of the index finger and the thumb itself are not supplied from the superficial arch since they receive branches from the radial artery.

Digital nerves

Lying immediately deep to the superficial palmar arch are the *common palmar digital nerves*. They pass distally to the webs, between the slips of the palmar aponeurosis and divide like the arteries (but proximal to the arterial divisions) into *proper palmar digital nerves*. Here the nerves lie superficially; they are destined essentially for the sensitive pads at the fingertips. They end dorsally by supplying all five nail beds (Fig. 2.49).

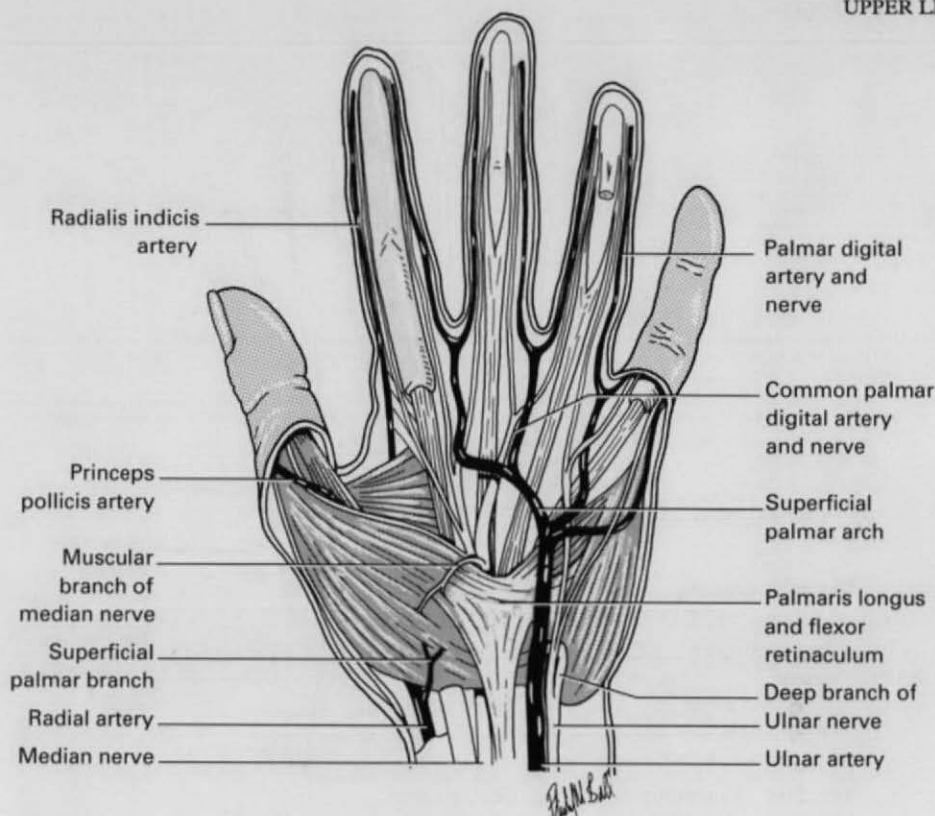


Fig. 2.48 Superficial palmar arch. The 'arch' is the curved continuation of the ulnar artery, and most commonly (as here) is not completed by union with a superficial palmar branch of the radial artery.

The digital arteries, lying dorsal to the digital nerves along the fingers, are directed towards the nail bed, where they are free from the pressure of gripping. Note that on going from the palm to the fingers the digital arteries and nerves swap places: in the palm the arteries are superficial (anterior) to the nerves, but on the sides of the fingers the nerves are anterior to the arteries.

The superficial branch of the **ulnar nerve** divides into two branches; the medial one supplies the ulnar side of the little finger, the lateral the cleft and adjacent sides of little and ring fingers (Fig. 2.49).

The **median nerve** enters the palm beneath the flexor retinaculum (Fig. 2.48) and divides into three branches. The *medial branch* divides into two and supplies palmar skin, the cleft and adjacent sides of ring and middle fingers and the cleft and adjacent sides of middle and index fingers (Fig. 2.49). The latter branch supplies the second lumbrical muscle. The *lateral branch* supplies palmar skin, the radial side of the index, the whole of the thumb and its web on the palmar surface and distal part of the dorsal surface. The branch to the index supplies the first lumbrical.

The highly important *muscular (recurrent) branch* curls upwards from around the distal border of the flexor retinaculum to supply the thenar muscles (p. 109). To reach these muscles the nerve passes superficial to the tendon of flexor pollicis longus. Incision of the sheath will endanger the nerve if the cut is not kept sufficiently distal.

Carpal tunnel syndrome

In the tightly crowded flexor tunnel the median nerve can be compressed, especially by long-continued swelling in the synovial sheaths. The symptoms include wasting and weakness of the thenar muscles (with loss of power of opposition of the thumb) and anaesthesia over three and a half digits on the thumb side of the hand. There is no anaesthesia over the thenar eminence itself, for this area of skin is supplied by the palmar branch of the median nerve, or occasionally by the lateral cutaneous nerve of the forearm. Either of these nerves enters the palm superficial to the retinaculum, and so escapes compression. Surgical division of the

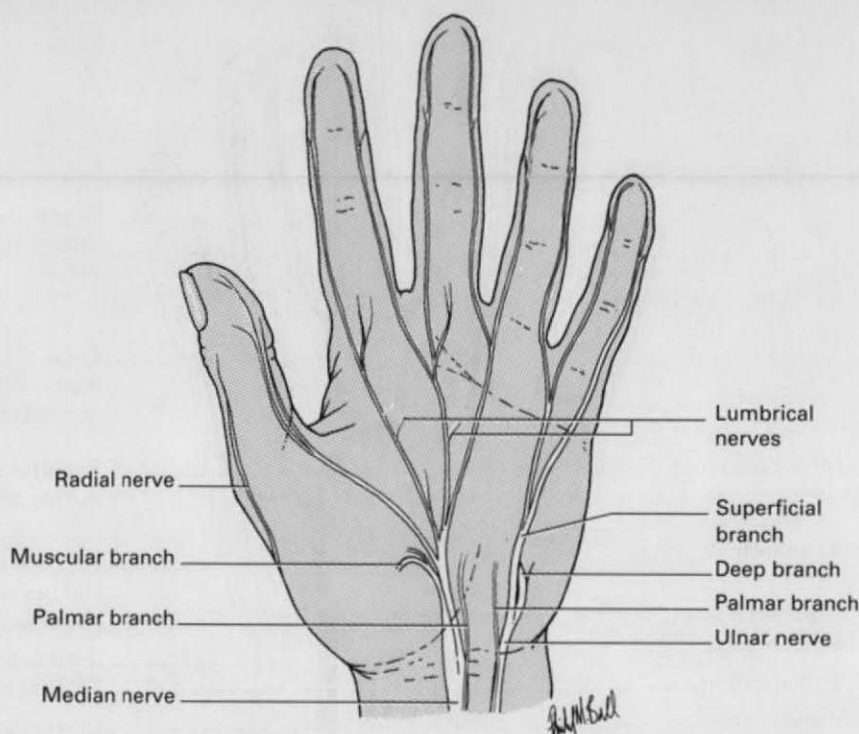


Fig. 2.49 Cutaneous innervation of the left palm.

retinaculum (p. 107) relieves the pressure and the symptoms.

The carpal tunnel syndrome must be distinguished from median nerve damage at a higher level. In the latter case the palmar cutaneous branch will be affected and, in addition, weakness of the relevant flexor muscles in the forearm (e.g. flexor pollicis longus) is a notable feature. In the carpal tunnel syndrome the terminal phalanx of the thumb can be flexed with normal power, but with higher lesions this power is lost.

Long flexor tendons

In the palm the tendons of flexor digitorum superficialis immediately overlie those of flexor digitorum profundus. From the latter tendons the four lumbrical muscles arise. The superficial tendons overlie the profundus tendons as they pass, in pairs, into the fibrous flexor sheaths of the fingers. Their synovial sheaths are considered on page 117.

Lumbrical muscles

From each of the four profundus tendons a lumbrical muscle passes along the radial side of the metacar-

pophalangeal joint (Fig. 2.47). On the palmar surface of the deep transverse metacarpal ligament, each develops a tendon which runs in a fibrous *lumbrical canal* to reach the extensor expansion on the dorsum of the first phalanx.

Nerve supply. Characteristically, the two ulnar lumbricals are innervated by the ulnar nerve and the two radial lumbricals by the median nerve (C8, T1). The proportion of ulnar and median distribution to the lumbricals follows that of the parent bellies of the tendons in the forearm (p. 91). It is interesting to note, though impossible to explain, that lumbricals supplied by the ulnar nerve are bicipital, each arising by two heads from adjacent profundus tendons, while those supplied by the median nerve are unicipital and arise from one tendon only.

Actions. See page 120.

Adductor pollicis

This muscle lies deeply in the palm (Figs 2.47 and 2.50) in contact with the metacarpals and interossei; it is not classified as part of the thenar eminence. The *transverse head* arises from the whole length of the palmar border of the third metacarpal

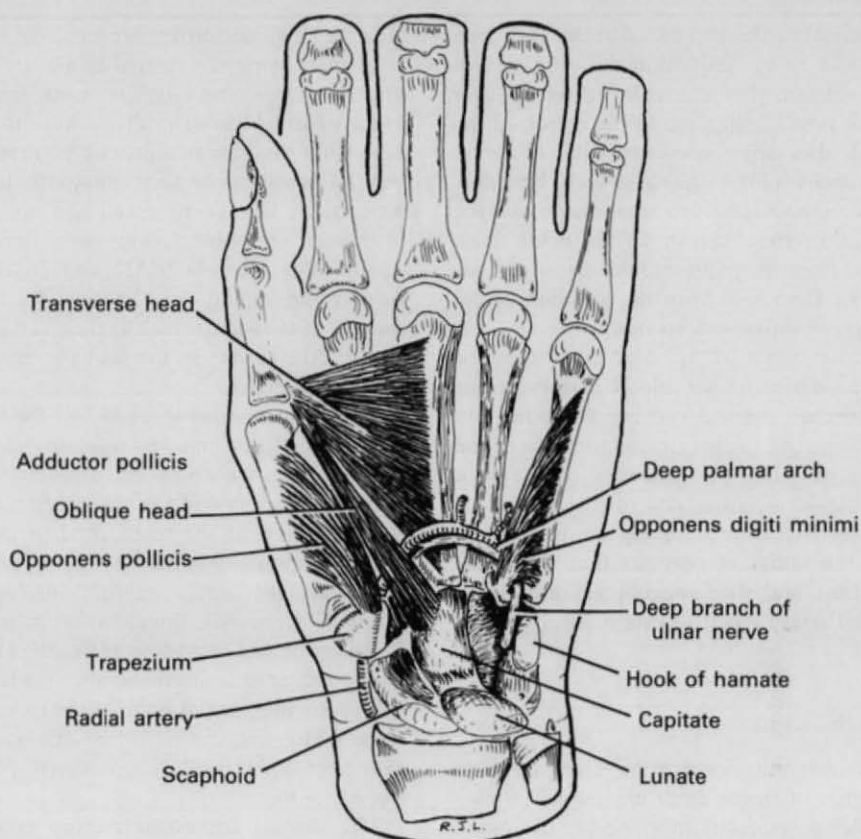


Fig. 2.50 Left adductor pollicis and the deep palmar arch. The two opponens muscles are also shown.

(Fig. 2.50) whence the muscle converges, fan-shaped, to the ulnar sesamoid of the thumb, and so to the ulnar side of the base of the proximal phalanx and the tendon of extensor pollicis longus. There is an *oblique head* (Fig. 2.50) that arises from the bases of the second and third metacarpals and their adjoining carpal bones (trapezoid and capitate) by a crescentic origin that embraces the insertion of flexor carpi radialis. The fibres of this head run edge to edge with the transverse head and converge with it on the ulnar sesamoid.

Nerve supply. By the deep branch of the ulnar nerve (C8, T1).

Action. To approximate the thumb to the index finger, whatever the original position of the thumb.

Radial artery in the hand

The radial artery leaves the lower end of the radius and slopes across the snuffbox over the trapezium and so

passes into the hand between the two heads of the first dorsal interosseous muscle (Fig. 2.42). Lying now between this muscle and adductor pollicis it gives off two large branches. The *arteria radialis indicis* passes distally between the two muscles to emerge on the radial side of the index finger, which it supplies. The *princeps pollicis* artery passes distally along the metacarpal bone of the thumb and divides into its two palmar digital branches at the metacarpal head. The main trunk of the radial artery now passes into the palm between the oblique and transverse heads of adductor pollicis to form the deep palmar arch (Fig. 2.33).

The **deep palmar arch** is an arterial arcade formed by the terminal branch of the radial artery anastomosing with the deep branch of the ulnar artery. Unlike the superficial arch (p. 110) the deep arch is usually complete. The radial artery gains the palm by passing between the oblique and transverse heads of adductor pollicis (Fig. 2.50), and runs across the palm at a level

about 1 cm proximal to the superficial arch. The deep branch of the ulnar nerve lies within the concavity of the deep arch. From its convexity three *palmar metacarpal arteries* pass distally and in the region of the metacarpal heads they anastomose with the common palmar digital branches of the superficial arch. Branches perforate the interosseous spaces to anastomose with the dorsal metacarpal arteries. Accompanying veins drain most of the blood from the palm into the dorsal venous network (p. 104). Branches from the anterior carpal arch also anastomose with the deep arch.

For a visual assessment of the contribution of the radial and ulnar arteries in the blood supply of the hand, make a clenched fist and occlude the radial and ulnar arteries. When the fist is released the skin of the palm is seen to be pale, but colour should return rapidly on the release of either one of the arteries. If there is an obvious delay after releasing the ulnar artery compared with the radial, it suggests that the radial supply is dominant and that procedures that might damage the radial artery (such as cannulation) should be avoided.

Ulnar nerve in the hand

The ulnar nerve leaves the forearm by emerging from beneath the tendon of flexor carpi ulnaris and passes distally on the flexor retinaculum alongside the radial border of the pisiform bone. Here it divides into superficial and deep branches (Fig. 2.48). The **superficial branch** supplies palmaris brevis and is then carried on as the *digital nerves* to the ulnar one and a half fingers. The small palmar branch supplies skin over the hypothenar muscles. The **deep branch** passes deeply into the palm *between* the heads of origin of flexor and abductor digiti minimi *and through* the origin of opponens digiti minimi (Fig. 2.50) to lie on the hook of the hamate, whose distal border it indents with a shallow groove. Passing down to the interossei, it arches deeply in the palm within the concavity of the deep palmar arch. It gives motor branches to the three hypothenar muscles, the two lumbricals on the ulnar side, all the interossei and both heads of adductor pollicis. Compare the ulnar nerve in the hand with the lateral plantar in the foot (p. 203). The cutaneous distribution is identical, but in the foot the superficial branch of the lateral plantar nerve, unlike that of the ulnar, supplies three muscles, and the deep branch supplies three instead of only two lumbricals.

Interosseous muscles

The interossei are in two groups, palmar and dorsal

(Fig. 2.51). The former are small and arise from only one (their own) metacarpal bone; the latter are larger and arise from the adjacent metacarpal bones of the space in which they lie. The palmar interossei are only seen from the palmar aspect of the interosseous spaces, but the dorsal can be seen from both dorsal and palmar aspects. It is easy to recall the attachments of the interossei by appreciating their functional requirements. The formula 'PAD and DAB' indicates that palmar adduct and dorsal abduct the fingers *relative to the axis of the palm*, which is the third metacarpal bone and middle finger (in the foot the axis passes through the second digit).

The **palmar interossei** adduct the fingers. Thus the thumb requires no palmar interosseous, already possessing its own powerful adductor pollicis muscle. Nevertheless a few fibres are sometimes found passing from the base of the metacarpal of the thumb to the base of its proximal phalanx; when present these fibres represent the first palmar interosseous muscle. Similarly the middle finger has no palmar interosseous; it cannot be adducted towards itself. The second, third and fourth palmar interossei arise from the *middle finger side* of the metacarpal bone of the index, ring and little fingers and are inserted into the same side of the extensor expansion and proximal phalanx of each respective finger.

The **dorsal interossei**, more powerful than the palmar, abduct their own fingers away from the midline of the palm (Fig. 2.51). The thumb and little finger already possess their proper abducting muscles in the thenar and hypothenar eminences. Thus there are dorsal interossei attached only to index, middle and ring fingers. In the case of index and ring fingers they are inserted into the side of the finger away from the middle finger. In the case of the middle finger itself a dorsal interosseous is present on each side. All four dorsal interossei arise by two heads, one from each bone bounding the interosseous space.

The tendons of palmar and dorsal interossei all pass on the posterior side of the deep transverse metacarpal ligament to reach their distal attachments. They are inserted chiefly into the appropriate side of the extensor expansion (like the lumbricals) (p. 118), but partly also into the base of the proximal phalanx (to which the lumbricals are *not* attached).

Nerve supply. All the interossei are supplied by the deep branch of the ulnar nerve (C8, T1), but an occasional variant is for the first dorsal interosseous to be supplied by the median nerve.

Actions. See page 118.

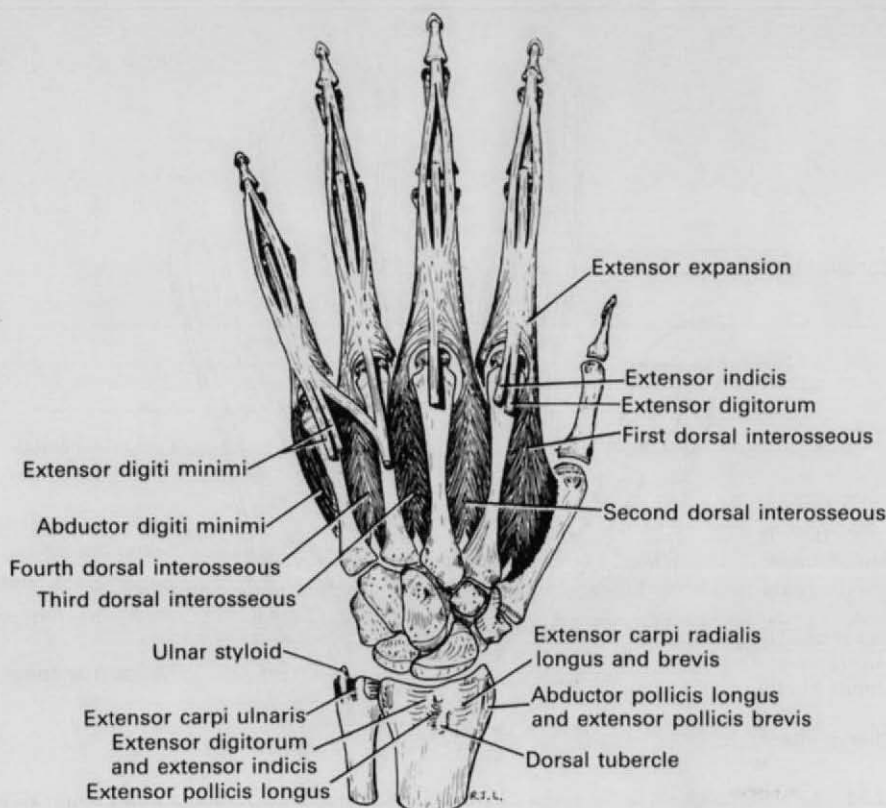


Fig. 2.51 Dorsal interossei of the left hand, with the dorsal digital expansions. Compare with Figure 2.44. The tendons occupying the grooves on the radius and ulna are named.

Fibrous flexor sheaths

From the metacarpal heads to the distal phalanges all five digits are provided with a strong unyielding fibrous sheath in which the flexor tendons lie (Fig. 2.47). In the thumb the fibrous sheath is occupied by the tendon of flexor pollicis longus alone. In the four fingers the sheaths are occupied by the tendons of the superficial and deep flexors, the superficial splitting to spiral around the deep within the sheath. The proximal ends of the fibrous sheaths of the fingers receive the insertions of the four slips of the palmar aponeurosis. The sheaths are strong and dense over the phalanges, weak and lax over the joints.

Synovial flexor sheaths

In the carpal tunnel the flexor tendons are invested with synovial sheaths that extend proximally into the lower part of the forearm and proceed distally to a varying extent (Fig. 2.52). On the tendon of flexor pollicis

longus the sheath extends from above the flexor retinaculum to the insertion of the tendon into the terminal phalanx of the thumb. The tendons of the superficial and deep flexors are together invested with a common synovial sheath that is incomplete on the radial side. This common sheath commences a short distance above the wrist and extends down into the palm. On the little finger, it is continued along the whole extent of the flexor tendons to the terminal phalanx. Next to the first, the fifth metacarpal is the most mobile bone of the palm. The common flexor sheath ends over the remaining three sets of tendons just distal to the flexor retinaculum. In the case of a very mobile fourth metacarpal the sheath may extend to the terminal phalanx of the ring finger, like that of the little finger in the average hand. The common flexor sheath communicates at the level of the wrist with the sheath of flexor pollicis longus in 50% of individuals. In the index, middle and ring fingers, where the common sheath ends beyond the flexor retinaculum, a separate synovial sheath lines the fibrous flexor sheath over the

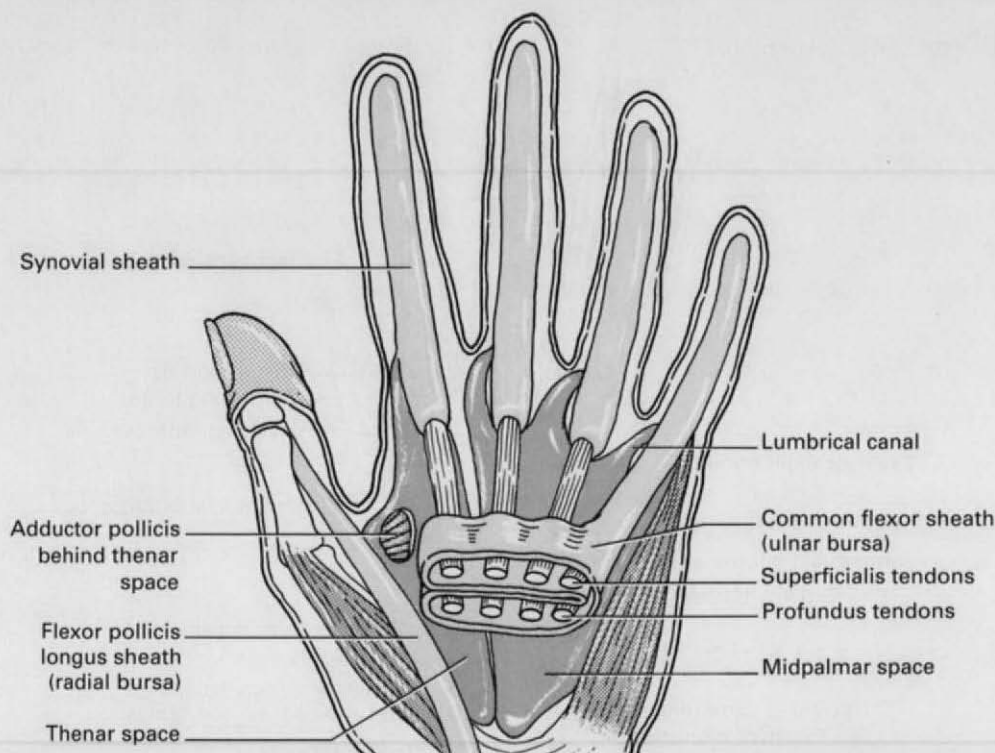


Fig. 2.52 Left palmar spaces and synovial sheaths. Infection in the thenar or midpalmar spaces easily breaks through into the lumbrical canals (connective tissue sheaths of the lumbrical muscles), so the canals are shown in continuity with the spaces. A segment of the ulnar bursa has been removed to indicate the disposition of the finger tendons embraced by it.

phalanges. There is thus a short distance of bare tendon for index, middle and ring fingers in the middle of the palm. It is from this situation that the lumbrical muscles arise. The fourth lumbrical obliterates the synovial sheath along its origin from the tendon to the little finger.

Palmar spaces

The palmar aponeurosis, fanning out from the distal border of the flexor retinaculum, is triangular in shape. From each of its two sides a fibrous septum dips downwards into the palm. That from the ulnar border is attached to the palmar border to the fifth metacarpal bone. Medial to it is the *hypothenar space*, not important surgically since it contains no long flexor tendons, but encloses only the hypothenar muscles. The remaining part of the palm is divided into two spaces by the septum that dips in from the radial border of the palmar aponeurosis to the palmar surface of the middle metacarpal bone. This septum lies obliquely and

separates the *thenar space* on its radial side from the *midpalmar space* beneath the palmar aponeurosis. Normally the septum passes deeply between the flexor tendons of index and middle fingers, i.e. the flexor tendons of the index finger overlie the thenar space. In some cases, however, the septum passes deeply between the index tendons and the first lumbrical; in these cases the first lumbrical overlies the thenar space whilst the flexor tendons to the index finger overlie the midpalmar space.

The **midpalmar space** is limited superficially by a thin fascia that lies deep to the common synovial sheath and the flexor tendons (Fig. 2.52). The space is floored in by interossei and metacarpals of the third and fourth spaces. Its sides are formed by the septa dipping in from the borders of the palmar aponeurosis. Infection in the space can readily break into the connective tissue canals surrounding the ulnar three lumbricals, so that for practical purposes the space may be considered to be continuous distally with these lumbrical canals. Proximally the space is closed by the firm attachment of

the parietal layer of the common flexor synovial sheath to the walls of the carpal flexor tunnel.

The **thenar space** lies on the thumb side of the septum that joins the border of the palmar aponeurosis to the palmar border of the third metacarpal bone (Fig. 2.52). It always contains the first lumbrical muscle, into whose canal infection can spread, as in the midpalmar space, and generally also it is overlaid by the flexor tendons to the index finger. In the palm, it is bounded posteriorly by adductor pollicis, but around the distal border of this muscle, in the web of the thumb, it is continuous with the slit-like space that lies between adductor pollicis and the first dorsal interosseous muscle. The thenar space is closed at the wrist, in a manner similar to the midpalmar space, by fusion of the parietal layer of the synovial sheaths with the walls of the carpal tunnel.

Web spaces

The three web spaces of the palm lie between the four slips of attachment of the palmar aponeurosis. From the skin edge they may be said to extend proximally as far as the metacarpophalangeal joints, a distance of about 4 cm. Between the palmar and dorsal layers of the skin lie the superficial and deep transverse ligaments of the palm, the digital vessels and nerves, and the tendons of the interossei and lumbricals on their way to the extensor expansions. The web is filled in with a packing of loose fibrofatty tissue.

The **superficial transverse metacarpal ligament** lies beneath the palmar skin across the free margins of the webs (Fig. 2.45). Its fibres lie transversely in a flat band, best developed on the radial side and thinning out over the more mobile little finger. Its two ends, and the parts that lie across the fibrous flexor sheaths, are continued along the sides of the fingers, tethering the skin to the phalanges. The ligament supports the fold of skin at the web (it is well developed in quadrupeds whose forefeet are webbed). The digital vessels and nerves lie immediately deep to the ligament, a point to be remembered in making web incisions for palmar space infections. Here the nerves lie on the palmar side of the arteries. The lumbrical tendon lies beneath the vessels, passing distally within the lumbrical canal into the radial side of the dorsal expansion of its own finger.

The **deep transverse metacarpal ligament** (Fig. 2.47) joins the palmar ligaments of the metacarpophalangeal joints (p. 120). It lies 3 cm proximal to the superficial transverse ligament.

The *interosseous tendons* lie on the *dorsal* side of the deep transverse ligament; the *lumbrical tendons* are on the *palmar* side (Fig. 2.47).

The **web of the thumb** lacks both superficial and deep transverse ligaments, a factor contributing to the mobility of the thumb. The deep fascia passes across from palmar to dorsal surfaces of the web and beneath it lie the transverse head of adductor pollicis and the first dorsal interosseous muscle. From the slit-like space between them emerge the radial indicis and princeps pollicis arteries. Each hugs its own digit and the central part of the web can be incised without risk to either vessel. The thenar space lies beneath the deep fascia on the palmar surface of adductor pollicis; the first lumbrical passes through the space to the radial side of the index finger.

Pulp spaces

The pulp spaces are on the palmar side of the tips of the fingers and thumb. They contain fatty tissue that is divided into numerous compartments by fibrous septa that pass between the distal phalanx and the skin. Terminal branches of the digital vessels course through the spaces and some of them supply the end of the distal phalanx (but not the epiphysis); infection of the pulp spaces may occlude these vessels and cause necrosis of the end of the bone. The pulp space is limited proximally by the firm adherence of the skin of the distal flexion crease to the underlying tissue; this prevents pulp infection from spreading proximally along the finger.

DIGITAL ATTACHMENTS OF THE LONG TENDONS

Flexor tendons

The tendon of flexor digitorum superficialis enters the fibrous flexor sheath on the palmar surface of the tendon of flexor digitorum profundus. It divides into two halves, which flatten a little and spiral around the profundus tendon and meet on its deep surface in a chiasma (a partial decussation). This forms a tendinous bed in which lies the profundus tendon. Distal to the chiasma the superficialis tendon is attached to the *sides* of the whole shaft of the *middle* phalanx (Fig. 2.53).

The profundus tendon enters the fibrous sheath deep to the superficialis tendon, then lies superficial to the partial decussation of the latter, before passing distally to reach the *base* of the *terminal* phalanx. In the flexor sheath both tendons are invested by a common synovial sheath that possesses parietal and visceral layers. Each tendon receives blood vessels from the palmar surface of the phalanges. The vessels are invested in synovial membrane. These vascular synovial folds are the

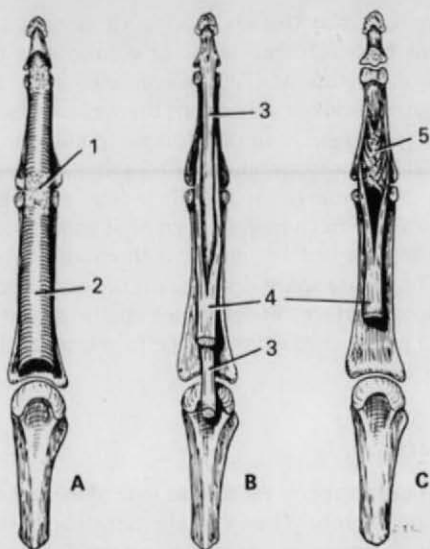


Fig. 2.53 Flexor tendon insertions. **A** Fibrous flexor sheath. Its fibres are oblique and slender across the interphalangeal (1) joints but transverse and strong across the phalanges (2). **B** Tendons exposed after removal of the sheath. The profundus tendon (3) perforates the superficialis tendon (4) to reach the base of the distal phalanx. **C** With the profundus tendon removed to show the gutter-shaped decussation (5) of the superficialis tendon (4) and the insertions into the sides of the palmar surface of the middle phalanx.

vincula, and each tendon possesses two, the short and long (Fig. 2.54). The profundus tendon has its short vinculum in the angle close to its insertion. Its long vinculum passes from the tendon between the two halves of the superficialis tendon (proximal to the chiasma) to the palmar surface of the proximal phalanx. The superficialis tendon has a short vinculum near its attachment into the sides of the middle phalanx. The long vinculum of the superficialis tendon is double, each half of the tendon possessing a vinculum just distal to its first division, passing down to the palmar surface of the proximal phalanx. The short vincula, attached to the capsules of the interphalangeal joints, serve to pull these out of harm's way during flexion. Only the long vinculum is vascular.

Extensor tendons and expansions

The extensor tendons to the four fingers have a characteristic insertion (Fig. 2.54). Passing across the metacarpophalangeal joint, the tendon is partly adherent to the articular margins, and indeed in this situation its deepest fibres form the posterior capsule of the joint. The bulk of the tendon, however, passes

freely across the joint, and broadens out on the dorsal surface of the proximal phalanx. This flat part now divides into three slips; the central slip passes on to the base of the middle phalanx. The two lateral or marginal slips diverge around the central slip. Each receives a strong attachment from the tendons of the interosseous and lumbrical muscles, forming a broad **dorsal digital** or **extensor expansion**. The palmar border of the extensor expansion is free and lies virtually in the long axis of the finger. More proximally the fibres from the interossei and lumbricals radiate across the dorsum of the proximal phalanx to complete the expansion, whose most proximal fibres pass transversely across the base of the phalanx. The fused interosseous tendons and marginal slips of the expansion, passing distally across the middle phalanx, converge to be inserted together into the base of the distal phalanx.

Certain fibrous bands are attached to the extensor apparatus; they are tightened by appropriate positions of the phalanges. The oblique **retinacular ligaments** are bilateral strong narrow bands attached near the head of

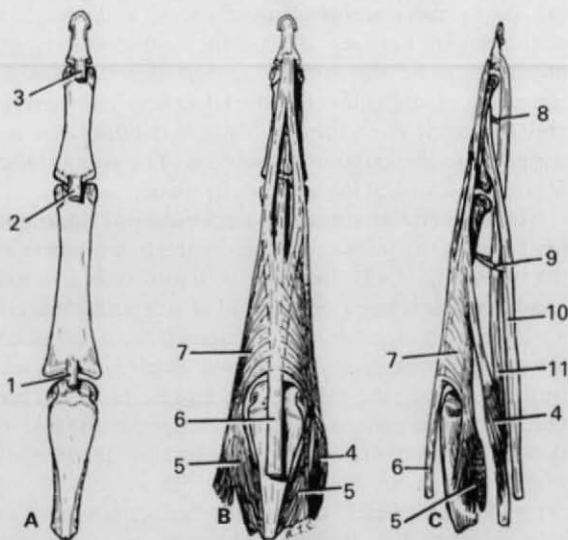


Fig. 2.54 Extensor digitorum tendon and the extensor expansion of the left middle finger. **A** Dorsal view showing insertions of the digitorum tendon into the base of each phalanx but the main attachments (2 and 3) are to the middle and distal phalanges, with a bursa (1) over the base of the proximal phalanx. **B** Dorsal view of the expansion. **C** View of the radial side. The lumbrical (4) is attached to the expansion (7) distal to the interosseous attachment (5). 1: part of bursa. 2 and 3: extensor attachments to middle and distal phalanges. 4: lumbrical muscle. 5: interosseous muscle. 6: extensor digitorum tendon. 7: extensor expansion. 8: long vincula to profundus tendon. 9: long vincula to superficialis tendon. 10: superficialis tendon. 11: profundus tendon.

the proximal phalanx, straddling the fibrous flexor sheath. Each passes palmar to the proximal interphalangeal joint and joins the marginal slip of the extensor tendon. Extension of the proximal joint draws them tight and limits flexion of the distal joint. Flexion of the proximal joint slackens them and permits full flexion of the distal joint. The two joints thus passively tend to assume similar angulations.

Long tendons of the thumb

On the flexor aspect there is only one tendon, that of flexor pollicis longus invested by its synovial sheath as it passes to the distal phalanx. On the extensor surface the tendons of extensor pollicis brevis and longus are each inserted separately (into the proximal and distal phalanx). There is no extensor hood as in the four fingers, but the extensor pollicis longus tendon receives a fibrous expansion from both abductor pollicis brevis and adductor pollicis (Fig. 2.42). These expansions serve to hold the long extensor tendon in place on the dorsum of the thumb.

Grip

Holding a heavy hammer for banging in a nail or holding a needle for delicate sewing (surgical or otherwise!) are but two illustrations of the variety of grips required for different purposes. For the labourer the *power grip* depends on the long flexors of the fingers, with opposition of the thumb assisting the whole hand to give a tight grip. At the same time synergic contraction of wrist extensors is indispensable for a firm grip of this kind; increasing flexion of the wrist increasingly weakens this grip (Fig. 2.55). In the *hook grip*, as for carrying a suitcase, the long flexors are in action but wrist extension and opposition may not be necessary accompaniments. The *precision grip* for dealing with small objects requires wrist stability, but opposition of the thumb to finger pads, especially of the index and middle fingers, are the essential features, and here the small hand muscles are of prime importance (see below).

Actions of interossei and lumbricals

The **interossei** are inserted into the proximal phalanges and into the extensor expansions. Contracting as palmar or dorsal groups, respectively, they adduct or abduct the fingers away from the midline of the palm. When palmar and dorsal interossei contract together the adducting and abducting effects cancel out. Flexion of the metacarpophalangeal joints results. The interossei are indispensable for the combined

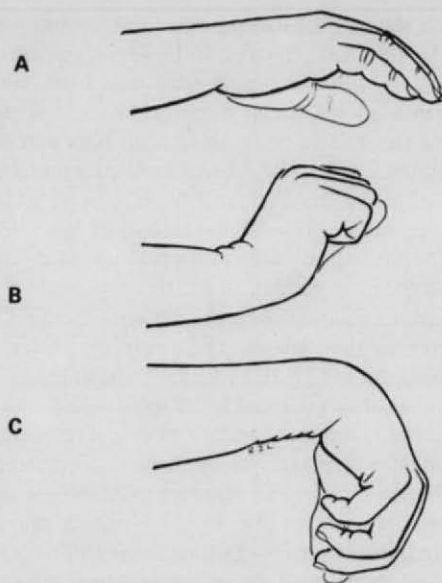


Fig. 2.55 Mechanism of gripping. **A** The right hand relaxed. **B** Synergic extension of the wrist accompanying 'making a fist'. **C** In the fully flexed wrist the grip is weak and it is not possible to make a fist.

movement of flexion of the metacarpophalangeal joint and simultaneous extension of the interphalangeal joints; but the manner of their action is not perfectly clear. Opposing theories exist. The earliest idea, a very simple one, was that the muscles act as prime movers, and this seems reasonable when one contemplates the anatomy of their insertions. The proximal fibres of the extensor hood run transversely across the first phalanx. Tension of these fibres will bend the phalanx towards the palm. The fibres on the edge of the dorsal expansion run almost along the axis of the finger, and are traceable distally to their insertion into the dorsal aspect of the base of the distal phalanx (Fig. 2.54). Tension on these fibres would naturally be expected to extend the distal phalanx. The difficulty in accepting this rather simple explanation is emphasized by the observation that extensor digitorum is indispensable to the action of extending the terminal phalanx with full force. In radial nerve palsy, or if the digitorum tendon is cut on the dorsum of the hand, the distal phalanx cannot be extended with full force even though the interossei are normal.

The probable explanation of the effect of the interossei on the terminal phalanges is that they are synergists to the prime mover, extensor digitorum. If the interossei are paralysed (claw hand) the pull of the digitorum tendon is wholly expended on the metacarpophalangeal joint which is hyperextended and there is

too much slack in the distal part of the tendon for it to act on the terminal phalanx. If, however, the metacarpophalangeal joint is flexed, the digitorum tendon, passing around its dorsal curve as around a pulley, lengthens the muscle belly, which can now extend the distal phalanx. Clinical evidence from peripheral nerve injuries of radial, median and ulnar nerves, indicates that the essential action of the interossei is to flex the metacarpophalangeal joints to allow extensor digitorum to extend the interphalangeal joints.

The action of the **lumbricals** is more obscure. Unlike the interossei, they are attached only to the extensor expansions and not to the proximal phalanges as well. Furthermore, their proximal attachments are not to bone but to tendons, and are therefore mobile. The lumbricals thus provide muscular, and hence proprioceptive, bridges between flexor and extensor muscles — a unique occurrence (as also in the foot) — which may have important implications in adjusting the positions of finger joints. In ulnar palsy all the interossei are paralysed but the lumbricals of only the little and ring fingers are out of action. The claw hand of ulnar paralysis affects these fingers most, index and middle fingers being less affected because their lumbrical muscles are intact (median nerve). From this fact and from their anatomical attachment into the extensor expansion it seems certain that the lumbricals have the same action as the interossei, namely to flex the metacarpophalangeal joints. In closing the fist the profundus tendon is withdrawn proximally into the palm as the terminal phalanx is flexed. This draws the lumbrical attachment proximally also; it seems absurd to imagine that in this simple movement the lumbrical actually *extends* the terminal phalanx, opposing the pull of its parent tendon. Here it surely acts simply through the extensor expansion as a flexor of the proximal phalanx.

Much work has been done on the actions of these little muscles, but it seems certain that the last word has by no means yet been said.

Tests. The first dorsal interosseous can be tested by abducting the index finger against resistance; the muscle can be seen and palpated between the first two metacarpals. The adducting capacity of the palmar interossei can be tested by trying to hold a piece of card between the adjacent extended fingers while an attempt is made to pull the card away. This test carried out between the index and middle fingers provides a reliable assessment of ulnar nerve integrity.

JOINTS OF THE CARPUS

An S-shaped **midcarpal joint** forms a continuous synovial space between the two rows of carpal bones,

and this extends proximally and distally between adjacent carpal bones as a continuous intercarpal joint. A similar synovial joint lies between the distal row of carpal bones and the metacarpal bones of the four fingers. This **carpometacarpal joint** commonly communicates with the midcarpal joint.

The joint between hamate and fifth metacarpal is the most mobile of the four and the slight flexion possible here aids in 'cupping' the palm. The **first carpometacarpal joint** (of the *thumb*) is a separate synovial cavity between the trapezium and first metacarpal bone. The joint surfaces are reciprocally saddle-shaped, to assist in the vitally important movement of opposition. The *capsule* is reinforced by a *lateral ligament* which passes from the lateral surface of the trapezium to the radial side of the base of the metacarpal, while converging on to the ulnar side of the metacarpal base are *palmar* and *dorsal ligaments* coming from those respective sides of the trapezium.

The **metacarpophalangeal joints** are synovial joints. They allow of flexion and extension, abduction and adduction. The *palmar ligaments* are strong pads of fibrocartilage, which limit extension at the joint. Those of the index to little fingers are joined together by transverse bands that together constitute the **deep transverse metacarpal ligament**, which receives at the sides of the metacarpophalangeal joints bands from the extensor expansion helping to keep the expansion centrally placed. The lumbricals and digital vessels and nerve lie on the *palmar* side of the deep transverse ligament and the interossei are *dorsal* to it (Fig. 2.47). These joints (the 'knuckle joints') lie on the arc of a circle; hence the extended fingers diverge from each other, the flexed fingers crowd together into the palm. A single finger flexed points in towards the tubercle of the scaphoid.

The **interphalangeal joints** are pure hinge joints, no abduction being possible. Extension is limited by palmar ligaments and by the obliquity of the collateral ligaments; the latter are attached eccentrically, and tighten in extension and in flexion. The joints act like a toggle switch (Fig. 2.56).

PART 10 SUMMARY OF UPPER LIMB INNERVATION

CUTANEOUS INNERVATION

The segmental supply (dermatomes) of the upper limb has been considered on page 22. Most of the cutaneous

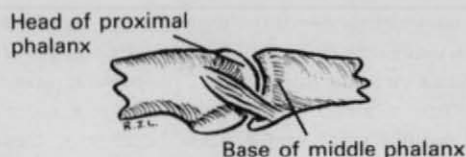


Fig. 2.56 Collateral ligament of an interphalangeal joint.

nerves have been described in the preceding pages but their distribution is summarized here (Fig. 2.57).

The skin over the shoulder is supplied by the supraclavicular nerves (C4) from the cervical plexus. This is neck skin that during development has moved on to the preaxial border of the root of the limb. Similarly, the postaxial border is clad with skin developed on the trunk. The floor of the axilla and a variable area of the medial surface of the arm is supplied by the lateral branch of the second intercostal nerve, the intercosto-

brachial nerve. Occasionally the lateral branch of the third intercostal nerve extends to supply skin on the floor of the axilla (Fig. 2.57).

The lateral surface of the arm is supplied by the upper lateral cutaneous and the lower lateral cutaneous nerves, branches of the axillary and radial nerves respectively. Posteriorly over the triceps a strip of skin is supplied by the posterior cutaneous nerve of the arm, a branch of the radial nerve. The intercostobrachial nerve and the medial cutaneous nerve of the arm supply the medial and anterior surfaces of the arm. It should be noted that the medial cutaneous nerve of the forearm supplies some skin of the arm just above the cubital fossa.

In the forearm a strip of skin posteriorly is supplied by the posterior cutaneous nerve of the forearm, a branch of the radial nerve. Medial and lateral sides are supplied by the medial and lateral cutaneous nerves of the forearm (from medial cord of the brachial plexus

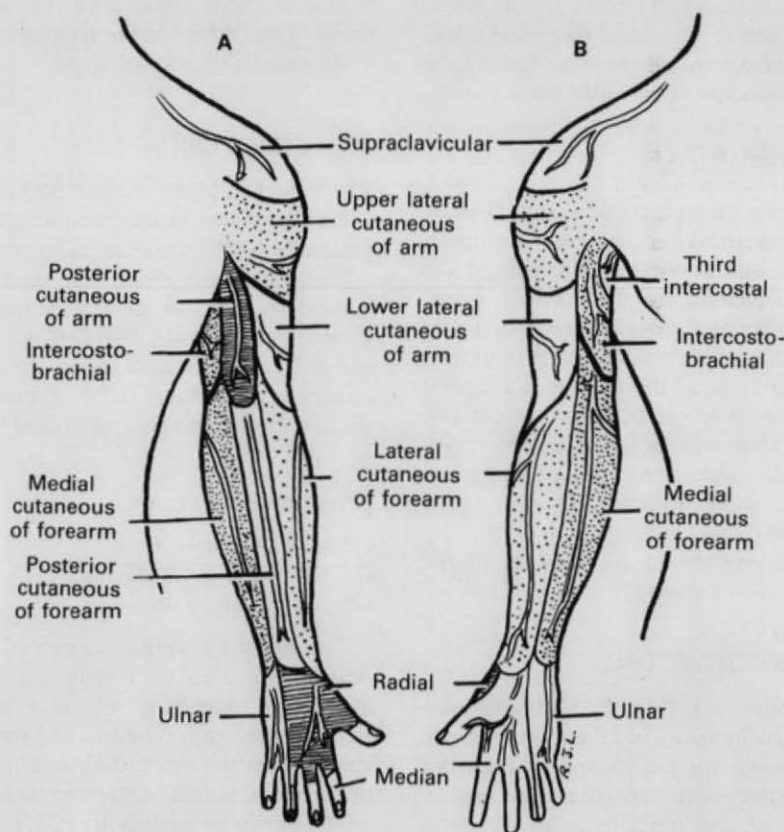


Fig. 2.57 Cutaneous nerves of the right upper limb, **A** from behind, **B** from the front. In these figures the intercostobrachial nerve replaces the medial cutaneous nerve of the arm, which is not uncommon. Compare with the dermatomes on Figure 1.16, page 23.

and musculocutaneous nerves respectively). Each of these divides symmetrically into anterior and posterior branches, which extend down to the wrist, and the anterior branch may just reach the palm.

The palm of the hand is supplied on the ulnar side by the superficial branches of the ulnar nerve. Towards the centre of the palm the skin is innervated by the palmar branch of the median nerve, which perforates the deep fascia proximal to the flexor retinaculum, with a small contribution from the palmar branch of the ulnar nerve over the hypothenar muscles. The palmar surfaces of the fingers and thumb are supplied by digital branches of the ulnar and median nerves. The ulnar digital branches supply the ulnar one and a half fingers on their palmar surfaces, their tips, and their dorsal surfaces over the distal one and a half phalanges. The median nerve by its digital branches supplies the radial three and a half digits on their palmar surfaces, tips, and dorsal surfaces over the distal one and a half phalanges. The dorsal surface of the hand is supplied on the ulnar side (one and a half fingers) by the dorsal branch of the ulnar nerve. The radial three and a half digits and the web of the thumb are supplied by the terminal cutaneous branches of the radial nerve.

MUSCULAR INNERVATION

In the upper arm the flexor compartment is supplied by the musculocutaneous nerve, the extensor compartment by the radial. The flexor compartment of the forearm is supplied chiefly by the median nerve, replaced by the ulnar for one and a half muscles (flexor carpi ulnaris and half of flexor digitorum profundus). The extensor compartment of the forearm is supplied by the radial nerve or its motor branch, the posterior interosseous. The intrinsic muscles of the hand are supplied chiefly by the ulnar nerve, the median nerve supplying only the three muscles of the thenar eminence and the radial two lumbricals.

The segmental innervation of the muscles of the upper limb is considered on page 27.

SYMPATHETIC INNERVATION

A grey ramus communicans (Fig. 1.21, p. 31) joins each root of the brachial plexus, and these sympathetic fibres hitch-hike through the plexus and its branches and remain in the nerves until very near their area of supply. For example the grey fibres to an arteriole in a fingertip run in the digital nerves and not along the digital arteries. The grey sympathetic fibres remain invariably with the same segmental fibres which they originally joined.

Thus each dermatome of the upper limb is supplied via the cutaneous nerves by hitch-hiking grey fibres from cell bodies in the appropriate sympathetic ganglion (dermatomes C5 and 6 from cell bodies in the middle cervical ganglion, C7 and 8 from the inferior cervical ganglion and T1 from the first thoracic, or stellate, ganglion). In the skin the grey rami innervate arterioles, sweat glands and the arrectores pilorum muscles (for temperature regulation).

The deep sympathetic supply to the limb is by a series of grey fibres that join the main artery from adjacent nerves. These form a periarterial plexus, but it is for only the local branches of the artery; the fibres in the periarterial plexus do not descend along the artery for any considerable distance. Thus, the operation of periarterial sympathectomy denervates only local branches of the artery, and has been long since abandoned for this reason.

The preganglionic fibres for the upper limb come mostly from cell bodies in the upper six thoracic segments of the spinal cord (but see p. 30 for variations). They ascend in the sympathetic trunk to synapse in the ganglia mentioned above.

BRACHIAL PLEXUS

The branches of the brachial plexus have been studied region by region in the previous pages, but it is convenient also to summarize each nerve as a whole.

The roots of the plexus (the anterior rami of C5–T1 nerves) are between the scalene muscles, the trunks in the posterior triangle, the divisions behind the clavicle, and the cords arranged round the second part of the axillary artery. About 10% of plexuses are pre-fixed (from C4–C8) and 10% post-fixed (C6–T2).

Branches of the roots

C5—Dorsal scapular

C5, 6—Nerve to subclavius

C5, 6, 7—Long thoracic

The dorsal scapular nerve (C5; pp. 59 and 67) runs down deep to levator scapulae and the two rhomboids, supplying all three muscles. Lying on serratus posterior superior, it forms a neurovascular bundle with the descending scapular vessels alongside the vertebral border of the scapula (Fig. 2.6).

The nerve to subclavius (C5, 6; p. 67) passes down over the trunks of the plexus and in front of the subclavian vein. If it contains accessory phrenic fibres these join the phrenic nerve in the superior mediastinum.

The long thoracic nerve (C5, 6, 7; p. 68) forms on

the first digitation of the serratus anterior muscle and runs vertically downwards just behind the midaxillary line, i.e. just behind the lateral cutaneous branches of the intercostal nerves and vessels, beneath the deep fascia over the muscle. Its fibres are paid off segmentally. C5 supplies the upper two digitations (which pull on the upper angle of the scapula), C6 the next two (vertebral border of scapula) and C7 the lowest four digitations (pulling on the inferior angle of the scapula, i.e. rotation of the scapula for abduction of the arm).

Branch of the upper trunk

The **suprascapular nerve** (C5, 6; p. 68), prominent beneath the fascial floor of the posterior triangle, passes beneath the transverse scapular ligament (the suprascapular vessels lie above the ligament). The neurovascular bundle supplies supraspinatus, infraspinatus, and the posterior part of the capsule of the shoulder joint.

Branches of the lateral cord

- C5, 6, 7—Lateral pectoral
- C5, 6, 7—Musculocutaneous
- C5, 6, 7—Lateral root of median

The **lateral pectoral nerve** (C5, 6, 7; p. 68) passes through the clavipectoral fascia and supplies the upper fibres of pectoralis major. Through the communication with the medial pectoral nerve it contributes to the supply of pectoralis minor.

The **musculocutaneous nerve** (C5, 6, 7; pp 68 and 81) is muscular to the flexors in the arm and cutaneous in the forearm. It supplies coracobrachialis, then pierces that muscle to slope down in the plane between biceps and brachialis, supplying both muscles. Emerging at the lateral border of the biceps tendon, it pierces the deep fascia at the flexure crease of the elbow. It is now called the *lateral cutaneous nerve of the forearm*, and supplies skin from elbow to wrist by an anterior and a posterior branch along the radial border of the forearm.

The **lateral root of the median nerve** (C5, 6, 7; pp. 68 and 81) is joined by the medial root at the lateral side of the axillary artery to form the main nerve (see below).

Branches of the medial cord

- C8, T1—Medial pectoral
- C8, T1—Medial root of median
- C8, T1—Medial cutaneous of arm
- C8, T1—Medial cutaneous of forearm
- C7, 8, T1—Ulnar

The **medial pectoral nerve** (C8, T1; p. 68) gives a branch to pectoralis minor and then pierces it to supply the lower (sternocostal) fibres of pectoralis major.

The **medial root of the median nerve** (C8, T1; pp. 68 and 81) crosses the axillary artery to join its companion and form the median nerve (C5–T1; pp. 81 and 94) at the lateral side of the artery.

The **median nerve** (C5, 6, 7, 8, T1; pp. 68, 81, 94 and 111) supplies most of the flexor muscles of the forearm, but only the three thenar muscles and two lumbricals in the hand. It is cutaneous to the flexor surfaces and nails of the three and a half radial digits and a corresponding area of palm.

The median nerve leaves the axilla and slopes in front of the brachial artery beneath the deep fascia of the arm. At the elbow it lies medial to the artery beneath the bicipital aponeurosis. It descends between the two heads of pronator teres and beneath the fibrous arch of flexor digitorum superficialis. Adherent to the deep surface of the muscle, it emerges on the radial side, lying between flexor carpi radialis and palmaris longus tendons before passing through the carpal tunnel into the hand.

Branches. In the arm the nerve gives sympathetic filaments to the brachial artery and a twig to the elbow joint, but no muscular branches unless the nerve to pronator teres has an unusually high origin. In the cubital fossa, it supplies *muscular branches* to pronator teres, palmaris longus, flexor carpi radialis and flexor digitorum superficialis, and also gives off the *anterior interosseous nerve*, which descends on the interosseous membrane to the wrist. The anterior interosseous is the nerve of the deep flexor compartment, for it supplies the radial half (usually) of flexor digitorum profundus, all of flexor pollicis longus and pronator quadratus and is sensory to the interosseous membrane, periosteum of radius and ulna, and the wrist and intercarpal joints. The *palmar cutaneous branch* of the median nerve pierces the deep fascia just above the flexor retinaculum and supplies more than half of the thumb side of the palm.

The median nerve divides in the carpal tunnel and enters the hand as a lateral and a medial branch. The lateral branch gives the important *muscular recurrent branch* (T1) which recurves around the distal border of the flexor retinaculum to supply the three thenar muscles (abductor and flexor pollicis brevis, and opponens pollicis). Then it breaks up into three palmar digital branches (C6), two for the thumb and one for the index, this last one supplying also the first lumbrical (T1). The medial branch divides into two palmar digital nerves for the adjacent sides of the second and third clefts (C7). The branch for the second cleft

supplies also the second lumbrical (T1). The five *palmar digital* branches supply the nail beds as well as the flexor skin of the radial three and a half digits.

The **medial cutaneous nerve of the arm** (C8, T1; pp. 68 and 82) is rather a failure. It is sometimes replaced entirely by the intercostobrachial nerve. It runs down with the axillary vein to pierce the deep fascia and supply skin medial to the anterior axial line, but fails to reach the elbow.

The **medial cutaneous nerve of the forearm** (C8, T1; pp. 68, 82 and 94) is a much bigger nerve than the last. It runs down between axillary artery and vein and pierces the deep fascia half way to the elbow (often in common with the basilic vein). It supplies the lower part of the arm above the elbow and then divides into anterior and posterior branches to supply the skin along the ulnar border of the forearm down to the wrist. In the forearm it is symmetrical with the lateral cutaneous nerve (musculocutaneous) and the two meet without overlap along the anterior axial line. Their territories are separated posteriorly by the posterior cutaneous branch of the radial nerve. The part of the nerve that lies in the upper arm can be used as a graft as this part is a long length without branches.

The **ulnar nerve** (C7, 8, T1; pp. 68, 82, 94 and 114) is the direct continuation of the medial cord (C8, T1). In 95% of cases it picks up C7 fibres in the axilla from the lateral cord (these fibres are for flexor carpi ulnaris). The nerve is destined for some flexor muscles on the ulnar side of the forearm and the skin of the ulnar one and a half digits, but it is to be remembered chiefly as the nerve for most of the intrinsic muscles of the hand (i.e. those concerned in fine finger movements).

Running down behind the brachial artery the ulnar nerve inclines backwards and pierces the medial intermuscular septum. Lying in front of the nerve to the medial head of triceps, it now descends along the triceps to lie on the shaft of the humerus between the medial epicondyle and the olecranon. It passes between the two heads of flexor carpi ulnaris and thus enters the flexor compartment of the forearm. Crossing the sublime tubercle, it descends on flexor digitorum profundus, under cover of flexor carpi ulnaris. Here it is joined by the ulnar artery. The two emerge from beneath the tendon of flexor carpi ulnaris just above the wrist and cross the flexor retinaculum alongside the pisiform bone. On the retinaculum the nerve divides into its terminal superficial and deep branches.

Branches. Several twigs to the elbow joint bind the nerve close against the lower end of the humerus. In the forearm the nerve supplies flexor carpi ulnaris (C7) and the ulnar half (usually) of flexor digitorum profundus (C8, T1). It has a *palmar cutaneous* branch (C8) which

pierces the deep fascia above the flexor retinaculum to supply skin over the hypothenar muscles. A *dorsal cutaneous* branch (C8) winds around the lower end of the ulna deep to the tendon of flexor carpi ulnaris, crosses the triquetral bone, and is distributed to the dorsal skin of one and a half fingers and a corresponding area of the back of the hand. On the fingers it falls short of the nail beds. Not uncommonly it supplies two and a half instead of one and a half fingers.

The ulnar nerve divides on the flexor retinaculum alongside the pisiform bone. The *superficial branch* (C8) runs distally beneath palmaris brevis (which it supplies) and is distributed to the ulnar one and a half fingers, including their nail beds, by two digital branches. One of them supplies the ulnar side of the little finger, the other goes to the fourth cleft, and bifurcates to supply the adjacent sides of ring and little fingers.

The *deep branch* (C8, T1) passes deeply between abductor and flexor digiti minimi then between opponens and the fifth metacarpal. It supplies all three hypothenar muscles. Crossing the palm in the concavity of the deep palmar arch it supplies the two ulnar lumbricals and all the interossei, both palmar and dorsal. It ends by supplying adductor pollicis.

Branches of the posterior cord

- C5, 6 — Upper subscapular
- C6, 7, 8 — Thoracodorsal
- C5, 6 — Lower subscapular
- C5, 6 — Axillary
- C5, 6, 7, 8, T1 — Radial

The **upper and lower subscapular nerves** (C5, 6; p. 68) supply the respective parts of subscapularis, with the lower nerve also innervating teres minor.

The **thoracodorsal nerve** (nerve to latissimus dorsi) (C6, 7, 8; p. 68) inclines forwards and enters the deep surface of latissimus dorsi just behind the anterior border; it is vulnerable in operations on the scapular lymph nodes, for its terminal part lies anterior to them and to the subscapular artery.

The **axillary nerve** (C5, 6; p. 69) supplies deltoid, the shoulder joint and skin over the joint. It passes backwards through the quadrangular space, lying above the posterior circumflex humeral vessels and in contact with the neck of the humerus just below the capsule of the shoulder joint, which it supplies. Through the quadrangular space it divides. The *posterior branch* supplies teres minor and winds around the posterior border of deltoid, supplying a small part of the muscle. As the *upper lateral cutaneous nerve of the arm* it supplies skin over the lower half of deltoid, below the supraclav-

icular nerves. The *anterior branch* lies on the *posterior* surface of the humerus between teres minor and the lateral head of triceps and supplies deltoid. A few fine twigs pierce the deltoid to reach a small area of skin over the centre of the muscle.

The **radial nerve** (C5, 6, 7, 8, T1; pp. 69, 83, 90 and 103) is the nerve of the extensor compartments of the arm and forearm, supplying skin over them and on the dorsum of the hand. Its branches tend to arise high above their destination.

A direct continuation of the posterior cord, the radial nerve passes beyond the posterior wall of the axilla and enters the triangular space below teres major. It spirals across the medial head of triceps to lie in the lower part of the radial groove on bare bone, deep to the lateral head of triceps. It pierces the lateral intermuscular septum and can be rolled on the humerus here, one-third of the way down from the deltoid tuberosity to the lateral epicondyle. In the flexor compartment of the lower arm it is held away from bare bone by brachialis, and it descends in the intermuscular slit between brachialis and brachioradialis. After giving off the posterior interosseous branch, the rather slender remnant, purely cutaneous now, retains the name of radial nerve. It runs down the flexor compartment of the forearm on supinator, the tendon of pronator teres, flexor digitorum superficialis, and flexor pollicis longus under cover of brachioradialis. It winds around the lower end of the radius deep to the tendon of brachioradialis, crosses abductor pollicis longus, extensor pollicis brevis and extensor pollicis longus (as one of the contents of the anatomical snuffbox) to reach the back of the hand. Here it divides into two or three to supply the skin of the radial three and a half digits (falling short of the nail beds) and a corresponding area of the dorsum. These nerves and the dorsal branch of the ulnar nerve commonly share the supply of $2\frac{1}{2} : 2\frac{1}{2}$ digits rather than the $3\frac{1}{2} : 1\frac{1}{2}$ usually quoted.

Branches. The *posterior cutaneous nerve of the arm* (C8 and all of T1 which the radial nerve carries) passes back medial to the long head of triceps and pierces the deep fascia to supply a strip of skin along the extensor surface of the arm down to the elbow. Although a three-headed muscle, triceps is supplied by *four* radial nerve branches. They arise as *nerves to the long, medial, lateral and medial heads*, usually in that order as the main nerve begins to wind round behind humerus. The first branch to the medial head (the *ulnar collateral nerve*) runs down behind the ulnar nerve to enter the lower part of the medial head. The second branch to the medial head continues deep to triceps to supply anconeus.

The *lower lateral cutaneous nerve of the arm* (C5) is given off just before the radial nerve pierces the lateral

intermuscular septum. It passes up to the skin between the septum and the lateral head of triceps to supply skin over the lateral surface of the arm down to the elbow. In common with it arises the *posterior cutaneous nerve of the forearm* (C6, 7), which runs straight down behind the elbow to supply a strip of skin over the extensor surface of the forearm as far as the wrist. (In the working position of pronation this skin faces towards the *front* of the body.)

While lying in the flexor compartment of the forearm between brachialis and brachioradialis, the main trunk gives a small branch to the lateral part of brachialis (not the main supply to this muscle) and supplies brachioradialis (C5, 6) and extensor carpi radialis longus (C6, 7). At the bend of the elbow it gives off the posterior interosseous branch, and then continues on as the terminal cutaneous branch already described.

The *posterior interosseous nerve* (C5, 6, 7, 8) supplies extensor carpi radialis brevis and supinator in the cubital fossa, and then spirals down around the upper end of the radius between the two layers of supinator to enter the extensor compartment of the forearm. It crosses abductor pollicis longus, dips down to the interosseous membrane and runs to the back of the wrist. In the extensor compartment it supplies seven more muscles; three extensors from the common extensor origin (extensor digitorum, extensor digiti minimi, and extensor carpi ulnaris), the three thumb muscles (abductor pollicis longus, extensor pollicis brevis and extensor pollicis longus) and extensor indicis. It is sensory to the interosseous membrane, periosteum of radius and ulna and the wrist and carpal joints on their extensor surfaces.

PART 11

SUMMARY OF UPPER LIMB NERVE INJURIES

In order to obtain a quick appraisal of the integrity of a major limb nerve it is not necessary to test every muscle supplied. Usually a key muscle and action can be selected that will indicate whether or not the nerve is intact. The following summary includes notes on selected nerve injuries and methods for exposing nerves if exploration or repair is required. (For a similar summary of lower limb nerve injuries see p. 214)

BRACHIAL PLEXUS

Damage to the *whole plexus* is rare but devastating. The

commonest cause is a motorbike accident, landing on the shoulder with the neck being forced in the opposite direction, so avulsing the nerve roots. If all the roots are damaged the whole limb is immobile and anaesthetic, and Horner's syndrome (p. 519) may be present. If serratus anterior and the rhomboids are still in action, the damage is distal to the root origins of the dorsal scapular and long thoracic nerves; if supraspinatus and infraspinatus escape, the damage is distal to the upper trunk.

The commonest *traction injury* to the plexus is to the upper roots and trunk (C5 and 6 — Erb's paralysis) and includes birth injury (Erb-Duchenne paralysis). The abductors and lateral rotators of the shoulder and the supinators are paralysed so that the arm hangs by the side, medially rotated, extended at the elbow and pronated, with loss of sensation on the lateral side of the arm and forearm.

Damage to the *lowest roots* (C8 and T1) is unusual (cervical rib) but includes Klumpke's paralysis due to birth injury during a breech delivery where the arm remains above the head. The small muscles of the hand are those most obviously affected, leading to 'claw hand' with inability to extend the fingers, with sensory loss on the ulnar side of the forearm and possibly a Horner's syndrome.

Pectoralis major, being the only muscle supplied by all five segments of the plexus, may be a useful guide to the extent of a plexus injury.

Surgical approach. The supraclavicular part of the plexus can be exposed in the angle between sternocleidomastoid and the clavicle. The inferior belly of omohyoid and the superficial cervical vessels are removed and the roots of the plexus are identified behind scalenus anterior, which may be cut (carefully avoiding damage to the phrenic nerve) to display the lower trunk. To expose the infraclavicular part, the deltopectoral groove is opened up and pectoralis minor detached from the coracoid process so that the plexus branches around the axillary artery can be dissected out from the axillary sheath. The middle part of the clavicle may have to be removed if a more proximal exposure is needed.

AXILLARY NERVE

The nerve may be damaged in 5% of dislocations of the shoulder, in fractures of the upper end of the humerus or by misplaced injections into deltoid. This muscle is paralysed and there may be an egg-shaped area of anaesthesia over the outer side of the upper arm below the acromion. Where possible, test for abduction of the shoulder by deltoid (p. 74), otherwise the area of anaesthesia gives the clue to the nerve damage.

MUSCULOCUTANEOUS NERVE

This nerve is rarely injured. Test for flexion of the elbow by biceps (p. 79). Beware of brachioradialis (radial nerve) simulating the flexor action of biceps and brachialis; biceps must be felt.

Surgical approach. Exposure of the nerve involves opening up the deltopectoral groove and identifying the nerve as it enters coracobrachialis from the lateral cord of the plexus, below the lower border of teres minor.

RADIAL NERVE

The nerve is most commonly injured high up, by fractures of the shaft of the humerus. Transient paralysis may be due to improper use of a crutch pressing on the nerve in the axilla, or 'Saturday night palsy' from draping the arm over a chair when in a state of diminished consciousness. The characteristic lesion is 'wrist drop' with inability to extend the wrist and metacarpophalangeal joints (but the interphalangeal joints can still be straightened by the action of the interossei and lumbricals). Sensory loss is minimal and usually confined to a coin-shaped area overlying the first dorsal interosseous, a much smaller area than the distribution of the nerve as seen in dissections; there is apparently much overlap from the median and ulnar nerves. For high injury test for extension of the elbow by triceps (p. 83), remembering that the branches to triceps arise before the nerve reaches the humerus. For injury at a lower level (e.g. posterior interosseous branch), test for extension of the wrist.

Surgical approach. The radial nerve in the arm may be exposed from the back by detaching the lateral head of triceps from the humerus to reveal the nerve as it crosses the upper part of the medial head before coming to lie in the radial groove. At the elbow brachioradialis and extensor carpi radialis longus are detached from the humerus and turned forwards to show the nerve dividing into its superficial and deep (posterior interosseous) branches. The superficial part of supinator can be incised if the deep branch has to be followed downwards.

ULNAR NERVE

This is most commonly injured behind the elbow or at the wrist. The classical sign of a low lesion is 'claw hand', with hyperextension of the metacarpophalangeal joints of the ring and little fingers and flexion of the interphalangeal joints because their interossei and lumbricals are paralysed and so cannot flex the metacarpophalangeal joints or extend the interpha-

langeal joints. The claw is produced by the unopposed action of the extensors and of flexor digitorum profundus. Injury at the elbow or above gives straighter fingers because the ulnar half of flexor digitorum profundus is now out of action and cannot flex the distal interphalangeal joints of the ring and little fingers. Wasting of interossei eventually becomes obvious on the dorsum of the hand, giving the appearance of 'guttering' between the metacarpals. There is variable sensory loss on the ulnar side of the hand and on the little and ring fingers but often less than might be expected.

As representative of the small muscles of the hand supplied by this nerve, test for abduction of the index finger by the first dorsal interosseous (p. 120). For a high lesion, test for the action of the ulnar half of flexor digitorum profundus in flexing the distal interphalangeal joint of the little finger (p. 91).

Surgical approach. Exposure of the ulnar nerve in the upper arm is along the medial border of biceps, where the nerve is adjacent to the brachial artery. At the elbow it is easily approached behind the medial epicondyle, and in the forearm it can be followed upwards from the pisiform, where it lies between the bone and ulnar artery, by displacing flexor carpi ulnaris medially.

MEDIAN NERVE

This is most commonly injured at the wrist — by cuts, or compression in the carpal tunnel. There is eventually wasting of the thenar eminence, but because of the variable nerve supply of flexor pollicis brevis the only obvious wasting may be over abductor pollicis brevis.

Theoretically there is sensory loss over the radial three fingers and radial side of the palm, but the only autonomous areas of median nerve supply are over the pulp pads of the index and middle fingers, and the actual sensory loss may be difficult to define. The most important areas of loss are over the pads of the thumb and index finger. With high lesions there is wasting of the front of the forearm because the long flexors (except flexor carpi ulnaris and half of flexor digitorum profundus) and the pronators are paralysed. The hand is held with the index finger straight, in the 'pointing finger' position, often with all other fingers flexed, including the middle finger. Although the part of flexor digitorum profundus to the middle finger tendon is expected to have a median supply (like the whole of superficialis), its close connexion with the part supplied by the ulnar nerve can lead to middle finger flexion. Furthermore, this part of the muscle may be supplied by the ulnar nerve and not the median. For high

lesions, test flexor pollicis longus and finger flexors by pinching together the pads of thumb and index finger. For lesions at wrist level, test abductor pollicis brevis (p. 110); do not choose flexor pollicis brevis because of its uncertain nerve supply.

Surgical approach. In the arm the median nerve is easily exposed by incision along the medial border of biceps, where the nerve is adjacent to the brachial artery, and in the cubital fossa it lies medial to the biceps tendon. In the forearm it is displayed by detaching the radial head of flexor digitorum superficialis from the radius and turning the muscle medially to show the nerve adhering to its deep surface. Relief of compression in the carpal tunnel involves incising the flexor retinaculum longitudinally on the ulnar side of the nerve, to avoid damage to the muscular (recurrent) branch which usually arises immediately distal to the retinaculum and curves radially into the thenar muscles.

PART 12

OSTEOLOGY OF THE UPPER LIMB

CLAVICLE

The **clavicle** (collar bone) is longer (14 cm plus) in the broad-shouldered male, and its curvatures are usually more pronounced than in the female. The medial two-thirds or more is rounded, rather quadrilateral in section and convex forwards to clear the neurovascular bundle of the upper limb, at the apex of the axilla (Fig. 2.12). The lateral one-third or less is flat, and curves back to meet the scapula. The upper surface is smoother than the lower, especially in the lateral flat part. The bone lies horizontally and is subcutaneous; it is crossed by the supraclavicular nerves and very occasionally by a communication between the external jugular and cephalic veins. The main parts are the shaft, the bulbous sternal end and the flattened acromial end.

The **sternal end** (Fig. 2.8) is occupied by a facet for the disc of the sternoclavicular joint. The disc is attached along the upper and posterior margin of the articular surface in a curved groove. The articular area below this extends to the under surface, for articulation with the first costal cartilage (Fig. 2.58). The articular surface is covered in life by fibrocartilage identical with that of the disc. The capsule and synovial membrane are attached around the margin of the articular surface.

On the *posterior surface* of the **shaft** the origin of sternohyoid extends in a line beyond the capsule

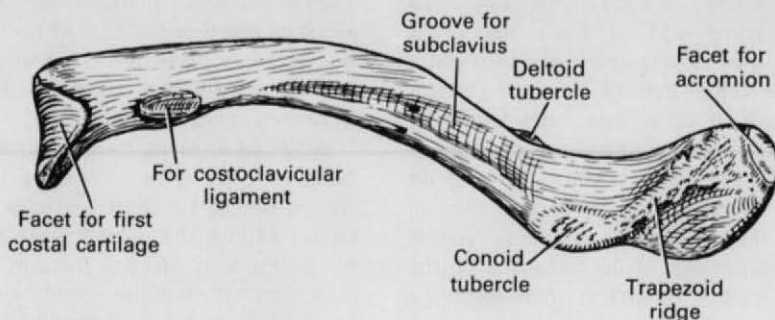


Fig. 2.58 Left clavicle, from below.

attachment, but leaves no mark on the bone. Lateral to this the subclavian vessels lie nearby, and further laterally the newly formed lateral cord of the brachial plexus lies behind bare bone (Fig. 2.12). Here the nutrient artery, a branch of the suprascapular, runs laterally into the bone. The posterior border of the flat lateral one-third gives attachment to the occipital fibres of trapezius; this muscle encroaches somewhat on the upper surface, leaving a polished mark. The lateral extremity shows a small overhanging oval facet for the acromioclavicular joint (p. 62).

Anteriorly the flat lateral one-third gives origin to deltoid, which muscle encroaches like trapezius somewhat on the upper surface, leaving a concave polished area limited by a low ridge. A 'deltoid' tubercle sometimes projects into the muscle near the medial limit of this origin. The anterior surface of the *medial half* of the clavicle is flattened slightly by the origin of pectoralis major, faint ridges marking the limits of attachment of the muscle. The cephalic vein lies below the gap between the deltoid and pectoral attachments.

The *upper surface* receives the interclavicular ligament alongside the capsule attachment. The clavicular head of sternocleidomastoid arises from a wide area on the medial one-third or more of this surface (Fig. 6.57, p. 523), but usually leaves no very apparent mark on the bone. Two layers of cervical fascia (p. 421) surround sternocleidomastoid and trapezius and are attached separately to the bone between these muscles, at the base of the posterior triangle (Fig. 2.3).

The *lower surface* shows some very characteristic features (Fig. 2.58). Lateral to the articular surface, which usually encroaches from the sternal end, there is an oval plateau (or a pit) for attachment of the costoclavicular ligament. From here a *groove for the subclavius muscle* extends as far as the conoid tubercle. A *nutrient foramen* commonly extends laterally in this groove. The

lips of the groove give attachment to the clavipectoral fascia (Fig. 2.3). The posterior lip extends to a prominent rounded boss, the *conoid tubercle*, near the posterior border of the flat part; it lies buried in the base of the conoid ligament (Fig. 2.9). The conoid tubercle lies close to the knuckle of the coracoid process. A synovial joint sometimes exists between the two bones, within the conoid ligament. From the conoid tubercle the rough irregular *trapezoid ridge* extends obliquely across the bone to end near the articular facet, and provides attachment for the strong trapezoid ligament (p. 62).

The **acromial end** is flat, with a facet on its lateral edge which faces laterally and slightly downwards for articulation with the acromion. The capsule and synovial membrane are attached to the margin of the articular surface, which like that at the sternal end is covered by fibrocartilage.

Fracture of the clavicle is common; the break is always between the costoclavicular and coracoclavicular ligaments, each of which is stronger than the clavicle itself.

Ossification. The bone appears in membrane before there is yet any cartilage in the embryo. It is the first bone of the skeleton. Two centres, which ossify at the fifth week, rapidly fuse; elongation, which occurs at the sternal end, is in secondary cartilage (p. 10). An epiphysis at the sternal end appears radiologically during the late teens and fuses during the twenties.

SCAPULA

The **scapula** (shoulder blade) is triangular. The lateral angle is thick to accommodate the glenoid cavity, and projected upwards into the rugged coracoid process (Fig. 2.9). The lateral border is thick down to the inferior angle. The rest of the blade is composed of thin, translucent bone. From the upper part of the dorsal surface a triangular spine projects back and

extends laterally as a curved plate of bone, the acromion, over the shoulder joint (Fig. 2.19).

The **costal surface** is concave, and marked by three or four ridges that converge from the medial border towards the lateral angle. These give attachment to fibrous septa from which the multipennate fibres of subscapularis arise. This muscle is attached to the concavity of the costal surface and to the *lateral border* of the scapula back to a sinuous ridge that runs down from the infraglenoid tubercle (see below). The thick bone of the lateral angle is bare, separated from the overlying muscle by the subscapularis bursa; the ridges have faded out here. Vascular foramina perforate the bone over the bare area. The medial margin of the costal surface receives the insertion of serratus anterior (Figs 2.10 and 2.11). The first two digitations are attached to a smooth, flat, elongated triangle from the superior angle down to the base of the spine. The next two digitations are thinned out from this level down to the inferior angle, while the last four digitations converge to a roughened area on the costal surface of the inferior angle. A ridge separates the attachment of serratus anterior from the concavity of the subscapularis origin, and this ridge gives attachment to the strong fascia on the surface of subscapularis.

The *upper border* of the blade slants down to the root of the coracoid process, where it dips into the little scapular notch, which lodges the suprascapular nerve. The notch is bridged by the transverse scapular ligament, and the inferior belly of omohyoid arises from this ligament and the nearby upper border of the blade. The fascia over subscapularis is attached along the upper border of the bone. The *medial (vertebral) border*, from superior to inferior angle, gives edge to edge attachment to levator scapulae, rhomboid minor and rhomboid major (p. 58).

The *lateral (axillary) border* extends from the glenoid cavity to the inferior angle. Just below the glenoid fossa it shows a rough triangular plateau, the infraglenoid tubercle (this may be depressed into a fossa), and this gives origin to the long head of triceps. From this area a sharp ridge runs down and turns over the dorsal surface of the inferior angle above the origin of teres major. Subscapularis arises from the groove on the costal surface of this ridge and its fascia is attached to the ridge (p. 63).

The **dorsal surface** of the blade is divided by the backwardly projecting spine into a small supraspinous and a large infraspinous fossa. The supraspinous fossa lodges supraspinatus, which muscle is covered in a strong fascia attached to the upper margin of the spine and the upper border of the blade. The muscle arises from the whole area of the spine and adjoining blade,

but not from the lateral angle. The large infraspinous fossa is concave on the under surface of the spine, and there is a groove alongside the lateral border, but between these two hollows the thin blade is convex in conformity with the concavity of the costal surface. Infraspinatus arises from the whole of this fossa (but not from the lateral angle). Teres major arises from a large oval area at the inferior angle, and teres minor from an elongated narrower area dorsal to the ridge on the lateral border (Fig. 2.16). This origin of teres minor is commonly bisected by a groove made by the circumflex scapular vessels. Infraspinatus and teres minor are covered by a thick fascia that is attached to bone at the margins of these two muscles. Along the ridge on the lateral border this attachment is shared with the fascia over subscapularis.

The **spine** is thick as it projects back from a horizontal attachment on the dorsal surface of the blade. It is twisted a little, so its posterior border slopes upwards towards the acromion. Its free lateral border curves widely out as a buttress to the inferior surface of the acromion, arching behind the upper part of the lateral angle. The suprascapular vessels and nerve run here to reach the infraspinous fossa. The **acromion** itself is rectangular, and carries the facet for the clavicle at the anterior end of its medial border (Fig. 2.59). The dorsal surface of the spine and acromion are subcutaneous and palpable. Along the medial border of the acromion and the upper margin of the spine is a bevelled surface, 5 mm wide, for the insertion of trapezius (Fig. 2.16). Some 3 cm short of the medial border of the scapula this curves down and laterally to form a lip on the inferior margin of the spine. This lip is sometimes called the 'deltoid' tubercle; it receives the lowermost fibres of trapezius, which converge here. The medial end of the spine, alongside the border of the blade, is triangular and smooth. The tendon of trapezius plays over it, lubricated by a bursa. The 'deltoid' tubercle, though made by the trapezius attachment, marks the beginning of the attachment of deltoid, for from this place the muscle arises along the inferior margin of the spine and, in continuity, from the posterior, lateral and anterior borders of the acromion up to the clavicular facet. Along its lateral border the acromion shows four or more vertical ridges (Fig. 2.59) for attachment of septa in the multipennate central mass of the deltoid muscle. The junction of lateral and anterior borders of the acromion, 2 cm lateral to the acromioclavicular joint, forms the prominent bony 'tip of the shoulder' (but not the most lateral part of the shoulder region, which is deltoid overlying the greater tuberosity of the humerus), and from here the length of the upper limb may be measured. In front of the facet

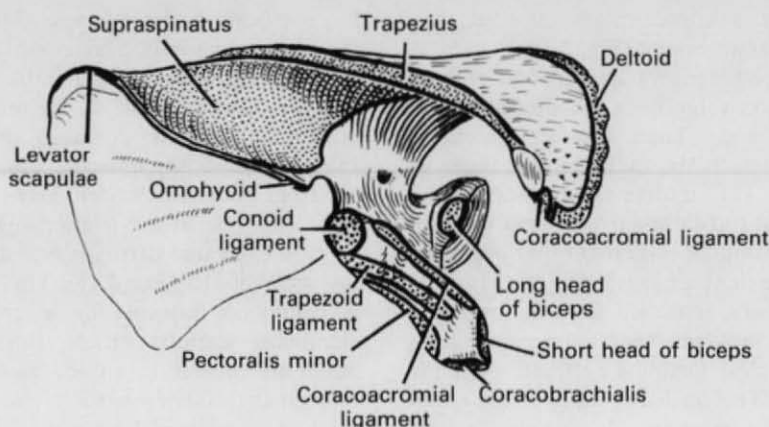


Fig. 2.59 Left scapula, from above.

for the clavicle the fibres of the coracoacromial ligament converge (Fig. 2.18). Beneath this ligament and the bare bone of the acromion the subacromial (subdeltoid) bursa lubricates the tendon of supraspinatus and the rotator cuff. Above the coracoacromial ligament the deltoid origin continues across the acromion (Fig. 2.59) to the lateral part of the clavicle.

The **lateral angle** of the scapula is wedge-shaped, broadening from the narrow neck out to the prominent margins of the **glenoid cavity**. The upper part of this wedge-shaped bone is projected upwards as the base of the coracoid process (Fig. 2.17). Two morphological elements are fused here (p. 53), and their epiphyseal junction crosses the upper part of the pear-shaped glenoid cavity (Fig. 2.9). The cavity does not face directly lateral, but peeps forwards a little around the convexity of the chest wall. The prominent lips of the cavity are raised higher by the attachment of the glenoid labrum. At the upper limit (the 'stem' of the pear), just on the base of the coracoid, lies the *supraglenoid tubercle*, for attachment of the long head of biceps within the shoulder joint capsule. The capsule is attached to the labrum and to the surrounding bone. The *infraglenoid tubercle* lies on the lateral angle, outside the capsule. There are no other attachments to the lateral angle, whose bare bone is perforated by nutrient vessels, and separated from the tendons of subscapularis, supraspinatus and infraspinatus by a bursa beneath each.

The **coracoid process** rises from its broad base and curves forward like a bent finger. Its tip is palpable by pressing backwards and laterally just below the clavicle, under cover of the anterior margin of deltoid. The process is for muscle and ligament attachments, the ligaments being indispensable to the stability of the pectoral girdle. The conoid ligament is attached by its

apex to the knuckle of the coracoid process (Fig. 2.59). From here a smooth narrow line runs towards the tip for attachment of the trapezoid ligament. Lateral to this the margin of the process gives attachment to the base of the coracoacromial ligament, which is a functional 'socket' for the head of the humerus. The weaker coracohumeral ligament sweeps from the under surface of the coracoid process to the anatomical neck of the humerus. The pectoralis minor is attached along the medial border of the coracoid process for about 2 cm behind its tip. The tip itself is bevelled to an arrow shape. From the lateral facet arises the tendon of the short head of biceps and, conjoined with it, from the medial facet comes the origin of coracobrachialis.

Ossification. Mesenchyme chondrifies at the sixth week, when the whole scapula becomes cartilaginous. A bony centre appears in the eighth week at the thick part of the lateral angle and gradually enlarges. At birth the blade and spine are ossified, but the acromion, coracoid process, medial border and inferior angle are still composed of hyaline cartilage. Secondary centres appear in these places, and around the lower margin of the glenoid cavity, at about puberty, and all are fused by 25 years. The centre at the base of the coracoid process ossifies at 10 years and fuses, across the glenoid cavity, soon after puberty.

HUMERUS

The shaft of the **humerus**, the bone of the arm, expands above into an upper end whose articular surface looks up and back (Fig. 2.61). The lower part of the shaft curves gently forwards to a flat lower end projected into medial and lateral epicondyles, between which lies the articular surface of the elbow joint (Fig. 2.25). The

medial epicondyle projects in the same direction as the articular surface of the head and is much more prominent than the lateral epicondyle. The humerus at rest lies with its articular head facing backwards as well as medially. *The bone on a table lies in some degree of lateral rotation.*

The **upper end**, expanded above the shaft, consists of the convex articular surface and, anterior to this, the tuberosities. The articular surface is the **head**, and the articular margin is the **anatomical neck**. It is the thickest, not the narrowest, part of the upper end. The commonsense 'neck', a common site for fracture, somewhat below the epiphyseal line, is at the upper end of the shaft and is referred to as the **surgical neck**; the axillary nerve winds round behind it.

The **head** (articular surface) forms about one-third of a sphere and is about four times the area of the glenoid cavity of the scapula. It is coated with hyaline cartilage. At rest its lower and anterior quadrant articulates with the glenoid cavity, giving a good range of lateral rotation and abduction from this position (confirm this point on the dry bones). In Figure 2.19 the humerus was deliberately drawn in slight lateral rotation, to expose more articular surface to view.

The capsule of the shoulder joint, bridging the bicipital groove at its attachment to the transverse ligament, is attached to the articular margin except medially, where it extends down along the shaft for 2 cm, here enclosing the epiphyseal line. The synovial membrane lines the capsule and is attached to the articular margin. The long tendon of biceps is enclosed in a sheath of synovial membrane, one end of which is attached to the transverse ligament and underlying articular margin (the other end of the sheath is attached around the supraglenoid tubercle of the scapula).

The **lesser tuberosity** (properly called the lesser tubercle) projects prominently forwards, and is continued downwards as the medial lip of the bicipital groove. An undulating area of smooth bone indicates the insertion of the tendon of subscapularis, while edge to edge below this teres major is received into the medial lip for a distance of nearly 5 cm (Fig. 2.10). The **intertubercular groove** (formerly the bicipital groove) lies on the anterior surface of the upper end (Fig. 2.60). It is bridged above by the transverse humeral ligament beneath which the long tendon of biceps leaves the joint (Fig. 2.18). The floor of the groove receives the ribbon-like tendon of latissimus dorsi.

The **greater tuberosity** (greater tubercle) is bare bone, perforated by vessels, except at its projecting junction with the head. Here three smooth facets receive the tendons of scapular muscles. Superiorly is the facet for supraspinatus (Fig. 2.60). Behind this lies

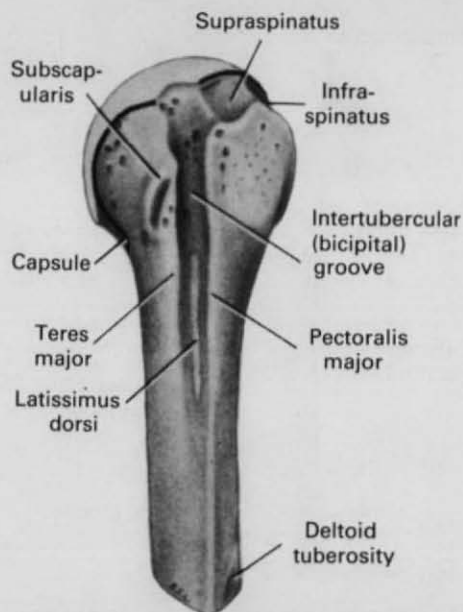


Fig. 2.60 Upper end of the left humerus, from the front.

a smooth facet for infraspinatus, while posteriorly the lowest facet receives teres minor (Fig. 2.61), whose tendon is inserted also into the shaft below the facet. Below this tendon the bare bone lies in contact with the axillary nerve and its vessels. The lateral lip of the bicipital groove extends down from the anterior margin of the greater tuberosity to run into the anterior margin of the deltoid tuberosity. It receives the folded tendon of pectoralis major, whose posterior lamina is attached as high up as the joint capsule (i.e. the anatomical neck). The anterior lamina extends only as high as the surgical neck.

Much of the **shaft** is triangular in section. Viewed from in front the lateral lip of the bicipital groove runs into the anterior margin of the deltoid tuberosity and is continued down in the midline of the bone. Lateral to this, the bare bone of the greater tuberosity continues down to the **deltoid tuberosity**, nearly halfway down the shaft. The tuberosity is a V-shaped prominent ridge, with a smaller ridge between, the three giving attachment to fibrous septa in the multipennate acromial fibres of the deltoid. Below the deltoid tuberosity the lower end of the **radial groove** spirals down. The posterior margin of the groove runs down as the lateral supracondylar ridge and curves forwards into the lateral epicondyle (Fig. 2.28). The ridge gives attachment to the lateral intermuscular septum. The medial lip of the bicipital groove continues down into the medial supra-

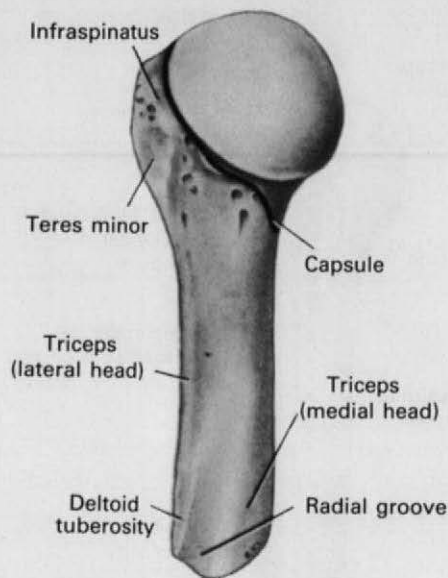


Fig. 2.61 Upper end of the left humerus, from behind.

condylar ridge, which at its lower end curves into the prominent medial epicondyle. The ridge gives attachment to the medial intermuscular septum. Level with the lower part of the deltoid tuberosity the nutrient foramen, directed down towards the elbow, lies just in front of this medial border of the humerus. Above this foramen, opposite the deltoid tuberosity, coracobrachialis is inserted and sometimes leaves a linear roughness. The flexor surface of the humerus, between the supracondylar ridges, gives origin to brachialis and this extends upwards to embrace the deltoid tuberosity both in the lower part of the spiral groove and between the tuberosity and the insertion of coracobrachialis. The occasional supratrochlear spur on this surface is mentioned on page 79.

Viewed from behind the shaft appears twisted, but this is due only to the radial groove behind and below the deltoid tuberosity. The lateral lip of this groove extends upwards from the posterior margin of the deltoid tuberosity; the lateral head of triceps arises here, extending up almost to the axillary nerve below the teres minor insertion. The lateral supracondylar ridge, as already noted, spirals up behind the radial groove to fade out on the posterior surface of the shaft level with the upper limit of the deltoid tuberosity. The medial head (i.e. the *deep* head) of triceps arises high up here and from the whole shaft between the supracondylar ridges down almost to the olecranon fossa. This head arises too from the medial and lateral intermuscular

septa (p. 82). Between the origins of medial and lateral heads the radial groove lies bare; only in its lowest part does the radial nerve lie in contact with the bone (p. 83). The profunda brachii vessels run with it.

The **lower end** of the humerus (Fig. 2.62) carries the articular surface for the elbow joint and is projected into medial and lateral epicondyles for attachment of muscles for the flexor and extensor compartments of the forearm (Fig. 2.25). Anterior and posterior appearances are quite different. The articular surface, coated with hyaline cartilage, shows the conjoined capitulum and trochlea. The *capitulum*, for articulation with the head of the radius, is a section of a sphere. It projects forwards and inferiorly from the lateral part and is bounded by a prominent ridge from the nonarticular bone. The *trochlea*, unlike the capitulum, extends also to the posterior surface. Its medial margin is a high ridge curving prominently from front to back around the lower end of the humerus, and this carries the side-to-side concavity of the trochlea with it into rather more than a semicircle. Laterally a lower ridge runs on into the capitulum in front and below. Behind this, beyond the capitulum, the ridge bounds the trochlea and arches over the olecranon fossa towards the medial epicondyle on the back of the bone. The difference in prominence

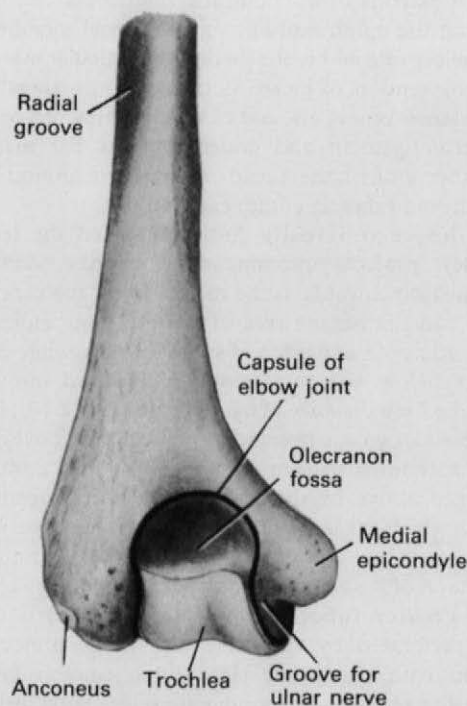


Fig. 2.62 Lower end of the left humerus, from behind.

between the two ridges gives a tilt to the trochlea which accounts for the carrying angle at the elbow.

On the anterior surface the shaft shows a shallow coronoid fossa separated by translucent bone from the depths of the olecranon fossa; this is above the concave part of the trochlea. The anterior border of the humerus runs down to the lateral ridge on the trochlea (Fig. 2.25) and here, above the capitulum, a shallow radial fossa accommodates the head of the radius in full flexion. The capsule of the elbow joint is attached to the ridges that form the margins of the capitulum and trochlea and to the shaft of the humerus above the coronoid and radial fossae in front and the olecranon fossa behind. The synovial membrane, as in all synovial joints, is attached to the articular margins. It thus clothes the floors of these fossae before being reflected to the deep surface of the capsule.

The **medial epicondyle**, more prominent than the lateral (Fig. 2.25), points in the same direction as the head of the humerus. It shows an undulating smooth facet on its anterior surface for the common flexor origin of forearm muscles. Pronator teres arises from the medial supracondylar ridge just above this. Posteriorly, between the smooth epicondyle and the curving ridge of the trochlea, is a groove which lodges the ulnar nerve (Fig. 2.62), here in contact with the *shaft* of the humerus (see Ossification, below). Deeply on the distal border of this epicondyle is a small facet for attachment of the ulnar collateral (medial) ligament of the elbow joint.

The **lateral epicondyle** shows an undulating smooth facet on its *anterior* surface for the common extensor origin of forearm muscles, i.e. extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi and extensor carpi ulnaris (p. 99). Above this the lateral supracondylar ridge gives attachment to the lateral intermuscular septum. Here brachioradialis arises from the upper two-thirds and extensor carpi radialis longus from the lower one-third of the ridge. At the distal border of the epicondyle the radial collateral (lateral) ligament of the elbow is attached, and around this the superficial fibres of supinator arise. Behind supinator is a shallow pit for anconeus, whose fibres arise also above this, in continuity with the lowest fibres of the medial (deep) head of triceps.

Surgical approach. The shaft can be exposed from the front by opening up the deltopectoral groove, and lower down by splitting brachialis vertically. The splitting incision is made anterolaterally and obliquely towards the middle of the front of the shaft, to keep well away from the brachial artery and median nerve. The radial nerve must be remembered when stripping periosteum from the lateral side of the lower part of the

shaft. Exposure of the shaft from behind involves opening up the interval between the long and lateral heads of triceps and splitting the medial head vertically in the midline, avoiding the profunda vessels and the radial nerve with its branches to triceps.

Ossification. The whole is cartilaginous at the sixth week. A primary centre appears in the centre of the shaft at the eighth week. Upper and lower ends are cartilaginous at birth. *Secondary centres* appear at both ends. For the *upper end* they are in the head during the first year, greater tuberosity at the third and lesser tuberosity at the fifth year. These three fuse by the seventh year into a single bony epiphysis, hollowed to fit a conical projection of the bony shaft. The epiphyseal line skirts the bone across the lowest margin of the articular surface, cutting across the tuberosities. This is the growing end of the bone; fusion occurs at about 20 years. At the *lower end* four centres appear. There is one for the capitulum and lateral ridge of the trochlea at the second year, one for the medial epicondyle at the fifth year, the remainder of the trochlea at the twelfth and the lateral epicondyle at the thirteenth year. The medial epicondyle remains a separate centre, separated by a downward projection of the shaft (in contact with the ulnar nerve) from the other three, which fuse together. Union with the shaft occurs at about 18 years.

RADIUS

This bone *carries the hand*, and is stabilized against the ulna for pronation-supination and against the humerus for flexion-extension of the forearm. From a cylindrical head the bone tapers into a narrow neck. The shaft becomes increasingly thick as it curves down to the massive lower extremity (Figs 2.63 and 2.64).

The **head** is cylindrical and is covered with hyaline cartilage. It is palpable in the depression behind the lateral side of the extended elbow, where it can be felt rotating in pronation-supination movements. A spherical hollow forms the upper surface, to fit the capitulum. The cylindrical circumference is continuous with this hollow, and is deepest on the medial side of the curvature; it articulates with the radial notch of the ulna and with the annular ligament. The synovial membrane of the elbow joint is attached to the articular margin, but head and neck are free of any capsule attachment, to rotate in the clasp of the annular ligament, which normally holds it in place; a sudden jerk on the hand of a child may avulse the head from the ligament, like pulling a cork out of a bottle. The narrow *neck* is enclosed by the tapered lower margin of the annular ligament, below which the loose fibres of the quadrate ligament are attached.

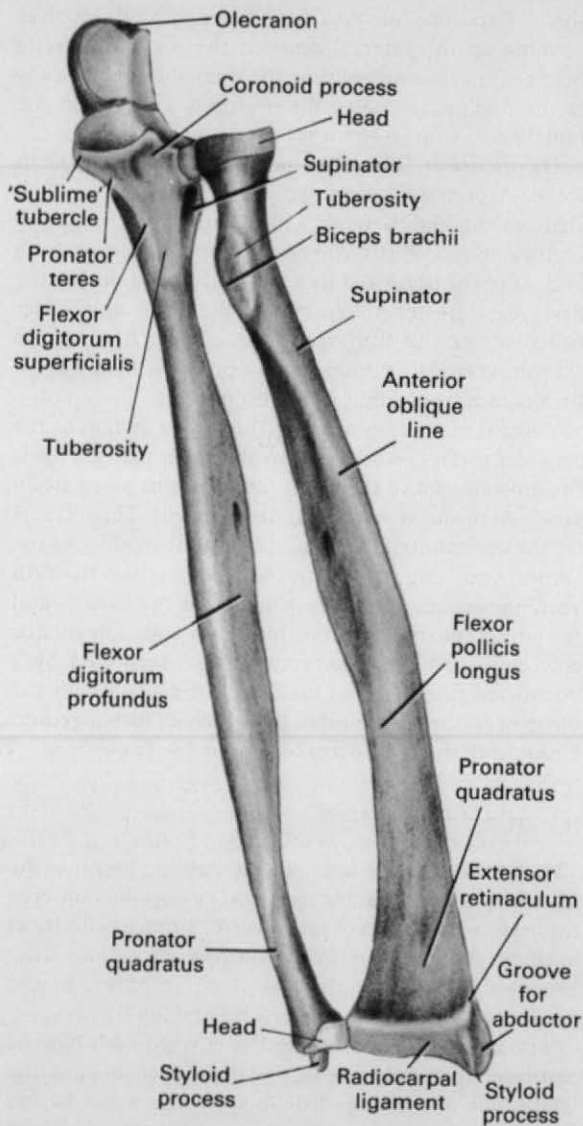


Fig. 2.63 Left radius and ulna, from the front.

The **shaft** is characterized at its upper end by an oval prominence, the radial tuberosity, projecting towards the ulna. The biceps tendon is attached along the posterior lip, and a bursa lies against the anterior surface of the tuberosity. In full pronation the tuberosity rotates back and looks laterally (Fig. 2.35), winding the biceps tendon around the radius. From the anterior margin of the tuberosity the anterior oblique line forms a ridge that runs down to the point of greatest convexity of the shaft. It is mirrored by a similar, but less prominent, posterior oblique line on the extensor surface of the shaft. Between the two

oblique lines the shaft is cylindrical and receives the insertion of supinator, with the posterior interosseous nerve off the bone, sandwiched between the two layers of the muscle. At the apex of the two lines is a longitudinal ridge or pit, 2 cm long, for the tendon of pronator teres. This lies at the point of greatest convexity of the radius, just *behind* the lateral profile of the supinated bone; invisible in a strictly anterior view, it shows in a posterior view of the radius (Fig. 2.64).

Below the tuberosity the shaft is pinched into a ridge for the interosseous membrane of the forearm. The

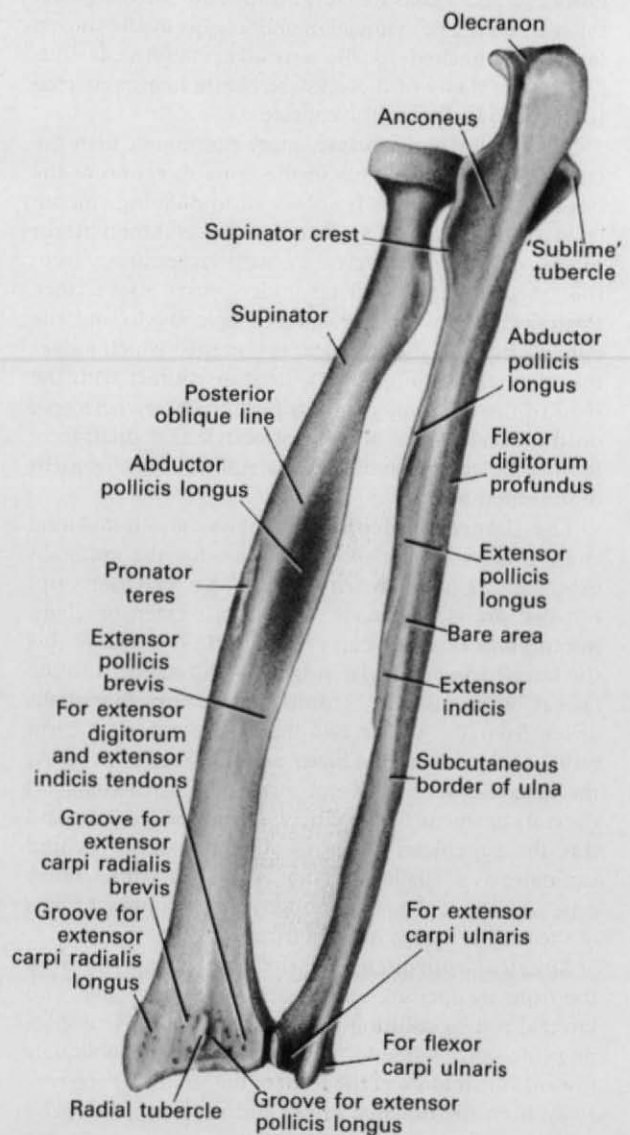


Fig. 2.64 Left radius and ulna, from behind.

oblique cord is attached at the upper end and passes up to the ulna; the fibres of the interosseous membrane pass *down* to the ulna. On the flexor surface the flexor digitorum superficialis is attached to the anterior oblique line, and flexor pollicis longus arises from a length of bone below this (and from the interosseous membrane) down to pronator quadratus. The lower part of the flexor surface is hollowed out above the expanded lower extremity; here pronator quadratus is inserted into the lower one-fifth of the shaft. On the extensor surface below the posterior oblique line is the oblique origin of abductor pollicis longus (this origin extends across the interosseous membrane up to the ulna). Below this extensor pollicis brevis arises obliquely from a slightly hollowed-out area and from the membrane. The lower part of the shaft is bare on the extensor surface (Fig. 2.41).

The **lower end** of the bone is expanded and is best studied surface by surface. The ulnar surface shows a notch for articulation with the head of the ulna. Above this is a triangular area enclosed by anterior and posterior ridges into which the interosseous border divides. The interosseous membrane is attached to the posterior ridge. In front of it lies the sacciform recess (p. 95) and then the deepest fibres of pronator quadratus are attached to the front of the triangle. Inferiorly is the articular surface for the wrist joint, two concave areas covered with hyaline cartilage. The ulnar (medial) surface is square, and articulates with the lunate. It continues into the hyaline cartilage of the ulnar notch, but in the intact wrist the triangular fibrocartilage is attached to the right-angled border between the two and divides the distal radioulnar and wrist joints from each other. The lateral concave area is triangular, with its apex on the styloid process. It articulates with the scaphoid. The capsule and synovial membrane are attached to the articular margins and to the fibrocartilage. The anterior (flexor) surface of the lower extremity shows a prominent ridge below the pronator quadratus hollow. Between this ridge and the articular margin is a smooth area to which is attached the very strong anterior ligament of the wrist joint. The fibres of this ligament pass *transversely* to the medial side of the carpus.

Laterally the lower end is projected into the pyramidal *styloid process*, to the tip of which the radial collateral ligament of the wrist joint is attached and into whose base the tendon of brachioradialis is inserted. Between this and the ridge of the pronator hollow the tendons of abductor pollicis longus and extensor pollicis brevis lie, in their synovial sheaths, in a single compartment beneath the extensor retinaculum. On the posterior surface beyond the styloid process a broad

groove leads to the prominent *dorsal tubercle* (of Lister). It lodges, each in a separate sheath, the flat tendons of extensors carpi radialis longus and brevis, sharing a single compartment beneath the extensor retinaculum. On the ulnar side of the dorsal tubercle is a narrow groove that lodges the tendon of extensor pollicis longus in its synovial sheath, in a separate compartment. Between this and the ulnar notch is another broad groove. In the one compartment lie the four tendons of extensor digitorum with the tendon of extensor indicis beneath them on the bare bone. All five tendons share a common synovial sheath. The tendon of extensor digiti minimi, in its sheath, crosses the radioulnar joint in a separate compartment.

The extensor retinaculum, a thickening of deep fascia, is attached to the prominent ridge on the lateral side of the pronator hollow (i.e. on the anterior surface of the radius, Fig. 2.33) and sweeps obliquely across to the ulnar side of the carpus. Septa pass from it to the radius, making compartments for the extensor tendons as noted above. Four compartments lie on the lower end of the radius, and a fifth over the radioulnar joint. The sixth and last compartment lies over the head of the ulna.

This expanded lower end takes the full thrust (via the thenar eminence) of a fall on the outstretched hand, and may lead to Colles' fracture of the lower end. The fibrocartilaginous disc is not torn but forms a fulcrum about which the characteristic deformities of the distal fragment occur: lateral rotation and displacement, dorsal rotation and displacement, supination and impaction.

Surgical approach. The head is exposed as for the lateral approach to the elbow joint (p. 85) by detaching the common extensor origin from the lateral epicondyle of the humerus and incising the capsule. The shaft is exposed from the front. At the upper end brachioradialis and the two radial extensors are mobilized laterally by cutting the radial recurrent artery and any relevant muscular branches; then supinator with its underlying periosteum is carefully detached from the bone, working laterally from the radial tuberosity with the posterior interosseous nerve sandwiched within the muscle. The nerve will not be damaged if the full thickness of the muscle with its periosteum is gently retracted from the bone. Lower down the shaft is exposed between brachioradialis laterally and flexor carpi radialis medially, while the lower end can be approached lateral to flexor carpi radialis by detaching pronator quadratus from the radius and turning it medially. Remember that the radial artery is lateral to the flexor carpi radialis tendon and the median nerve medial to it.

Ossification. The whole appears in cartilage at the sixth week, and a centre appears in the middle of the shaft at the eighth week. At birth both ends are cartilaginous; the lower is the growing end. A centre appears in the lower end at the end of the first year, and fuses at 20 years. This epiphyseal line is extracapsular; it runs transversely through the base of the styloid process and lies above the ulnar notch. The centre for the head appears at 4 years and fuses at 12; the epiphyseal line is at the junction of head and neck.

ULNA

This is the stabilizing bone of the forearm. It obtains a good grip of the humerus, and on this foundation the radius and hand move in pronation-supination to secure the appropriate working position for the hand. The ulna tapers in the reverse way to the radius; it is massive above and small at its distal extremity, where the head is situated (the head of the radius is at its upper end) (Figs 2.63 and 2.64).

The **upper end** has two projections, with a saddle-shaped articular surface between them. They are the olecranon and coronoid process, and they grip the trochlear surface of the humerus.

The **olecranon** is the proximal extension of the shaft, subcutaneous and easily palpable, and in extension of the elbow it is lodged in the olecranon fossa of the humerus. Its upper surface is square, and receives the tendon of triceps over a wide area, which is smooth. Its anterior border forms a sharp undulating lip at the articular margin; the capsule of the elbow joint is attached just behind this lip. The posterior surface, triangular in shape, is subcutaneous; the olecranon bursa lies on it. The sides of the triangle are continued below the apex into the sinuous subcutaneous border of the shaft; they give attachment to the deep fascia of the forearm. The medial surface of the olecranon, gently concave, is continued down to the flexor surface of the shaft. The upper fibres of flexor digitorum profundus arise here, covered by the thin sheet of flexor carpi ulnaris, whose ulnar origin is by an aponeurosis that extends up to the medial side of the subcutaneous triangle (Fig. 2.39). At the upper angle of this area is a small smooth facet for the posterior band of the ulnar collateral (medial) ligament of the elbow (Fig. 2.26). The lateral surface of the olecranon continues down to the extensor surface of the shaft; anconeus is inserted here (Fig. 2.41).

The **coronoid process** projects forwards from the upper end of the shaft. Its anterior lip, like that of the olecranon, is thin and abuts on the articular margin. Medially this lip shows a prominent smooth elevation,

the 'sublime' tubercle. Flexor digitorum superficialis is attached here, and beneath this the ulnar collateral (medial) ligament of the elbow. The ulnar nerve lies in contact with the sublime tubercle (Fig. 2.27). The anterior surface of the coronoid process is concave and receives the insertion of brachialis, the rough lower part of this surface forming the **ulnar tuberosity**. The medial border of the process gives a linear origin to the deep head of pronator teres. An occasional origin is given to flexor pollicis longus from either border of the coronoid process.

The lateral surface of the coronoid process carries a concave cylindrical facet, the radial notch, for the head of the radius and this surface, covered with hyaline cartilage, continues into that of the trochlear surface. The anterior and posterior margins of the notch give attachment to the annular ligament, while the quadrate ligament is attached to the shaft just below the notch. Just below this the oblique cord is attached.

Between the projections of the olecranon and coronoid process is a deeply saddle-shaped surface, the **trochlear notch**. Convex from side to side, it is concave from top to bottom and fits the trochlea of the humerus. It is covered with hyaline cartilage, which is sometimes constricted in hour-glass shape or even separated into two surfaces, one on the olecranon and one on the coronoid process. The capsule and synovial membrane of the elbow joint are attached around the margins of the trochlear notch and extend to the radial notch. Thus the elbow and proximal radioulnar joints form one cavity.

The **shaft** is angled somewhat laterally from the line of the trochlear notch (Fig. 2.35) to form the carrying angle. It is projected at its middle into a prominent ridge, the **interosseous border**. The ridge fades out at the lower one-fifth of the shaft, but is continued up to the posterior lip of the radial notch. Here, just below the notch, the ridge is prominent and is named the **supinator crest**. Between it and the lower part of the coronoid process is a concavity that can well be called the supinator fossa. The ulnar fibres of the supinator muscle arise from the crest and the fossa. The interosseous membrane is attached to the sharp interosseous border and extends down to the distal radioulnar joint. This divides the shaft into a narrow flat extensor surface passing to the nearby *subcutaneous border*, and an extensive convex flexor surface passing around to the same border. Only two muscles are attached to the flexor surface. Flexor digitorum profundus, the most massive muscle of the forearm, arises high on the medial concavity of the olecranon and from the upper three-quarters of the shaft between subcutaneous and interosseous borders, and from the

interosseous membrane. The bulky upper part of the belly curves the subcutaneous border into a convexity towards the radius. The subcutaneous border recovers from this curvature and extends vertically down to the styloid process. This border gives attachment to the aponeurotic head of flexor carpi ulnaris in its upper three-quarters and to the deep fascia of the forearm in its whole length. Running up from the anterior part of the styloid process is a ridge that dies out in the lower one-fifth of the shaft. Pronator quadratus arises from the radial side of this ridge and passes transversely beneath the long flexor tendons (Fig. 2.33). The narrow flat *extensor surface* lies between the interosseous and subcutaneous borders. It extends down from the lateral surface of the olecranon. Anconeus is received into its upper part. Below this a vertical ridge divides the surface. Between the ridge and the interosseous border three muscles leave shallow impressions on the bone — abductor pollicis longus, extensor pollicis longus and extensor indicis (Fig. 2.41). Between the ridge and the subcutaneous border the bone is bare; extensor carpi ulnaris plays over it. This muscle has an aponeurotic origin from the subcutaneous border below the insertion of anconeus.

The **lower end** expands into a small rounded prominence, the **head** of the ulna. Its distal surface and more than half of its radial circumference, covered with hyaline cartilage, form the distal radioulnar joint. A small pit at the base of the styloid process gives attachment to the apex of triangular fibrocartilage whose base is attached to the radius. This divides off the wrist joint, for the capsule is attached to the fibrocartilage. The capsule and synovial membrane of the distal radio-ulnar joint are attached around the articular margins but project proximally a little, deep to pronator quadratus, as the sacciform recess. The styloid process projects distally as a continuation of the subcutaneous border. Judged from the axis of the forearm it does not project distally as far as the radial styloid, but with the *supinated* forearm hanging free the carrying angle at the elbow gives an obliquity to radius and ulna that results in the two styloid processes lying at the same horizontal level (Fig. 2.63). The ulnar collateral (medial) ligament of the wrist joint is attached to the tip of the styloid process. A groove alongside the process, on the extensor surface, lodges the tendon of extensor carpi ulnaris, in its sheath, beneath the extensor retinaculum (Fig. 2.41).

Surgical approach. Being subcutaneous at the back, the bone is easily exposed by incising along the posterior border. The periosteum is elevated and the aponeurotic origins of flexors carpi ulnaris and digitorum profundus retracted medially and that of extensor carpi ulnaris retracted laterally.

Ossification. Cartilage at the sixth week, a centre for the shaft appears at the eighth week. The head is not ossified until the sixth year. This is the growing end and does not fuse with the shaft until 20 years. The upper end is curious in that it shows only a small epiphysis at the proximal surface of the olecranon; this appears at about the tenth year and fuses at 18 years or earlier. The massive upper end of the ulna grows in size and adapts its shape to the trochlea as one mass of bone, unaided by growth and adjustment at an epiphyseal line.

BONES OF THE HAND

The wrist and hand bones should be studied in an accurately articulated specimen, to see the pattern of the skeleton as a whole. The purpose of such study is twofold: to become acquainted with the places of attachment of ligaments, tendons and muscles, and to analyse the movements that occur between the bones. The old-fashioned necessity to tell an examiner to which side an isolated carpal bone belongs, memorized for the occasion and rightly forgotten after the event, has happily disappeared from modern curricula.

It is better first to study only the bony features (Figs. 2.65–2.69), then afterwards note the places of attachment of soft parts. The articulated bones are seen to form a carpus (eight bones), a metacarpus of five bones articulated with it, and the phalanges of the five digits articulated with the metacarpal heads. Their morphology is discussed on page 236.

CARPUS

The eight wrist bones articulated together form a semicircle, the convexity of which is proximal and articulates with the forearm. The diameter of the semicircle is distal, and articulates with the metacarpal bases (Fig. 2.66). The flexor surface of the carpus is deeply concave to accommodate the flexor tendons

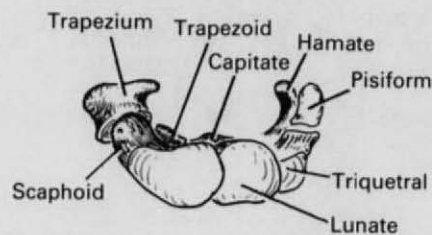


Fig. 2.65 Left carpus, looking distally towards the palm.

(Fig. 2.65). The extensor surface is gently convex and the extensor tendons pass across it.

The eight carpal bones lie in two rows. The proximal row consists of the scaphoid, lunate and triquetral, which together form the convexity of the semicircle. The fourth bone, the pisiform, completes the proximal row by articulating with the front of the triquetral, and so builds up the flexor concavity of the carpus. The palmar concavity of the carpus is maintained by the 'tie-beam' effect of the flexor retinaculum (p. 107 and Fig. 2.46).

The scaphoid and lunate together articulate with the radius, to whose distal extremity they are bound by strong ligaments. The triquetral, carrying the pisiform, articulates with the medial ligament of the wrist joint. Thus in pronation-supination the carpus moves with the radius, and upward thrust from the hand is carried wholly to the lower end of the radius, not at all to the head of the ulna. The cavity of the wrist joint, formed

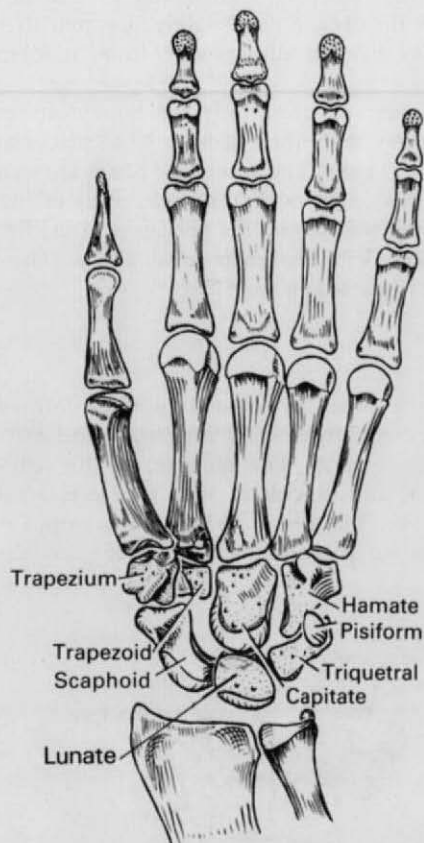


Fig. 2.66 Bones of the left hand, palmar surface, with the bones slightly separated to give a fuller view of each.

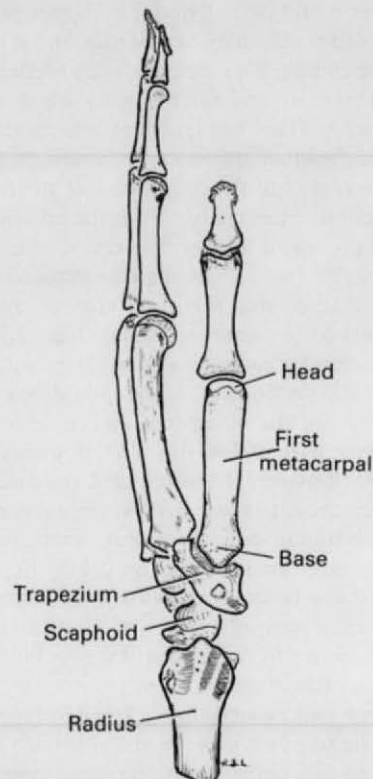


Fig. 2.67 Bones of the left hand, from the radial side.

by radius and fibrocartilage, is completed by the three proximal bones. The pisiform articulates with the triquetral by a separate synovial joint. The resting position of the wrist joint is in adduction, the carrying angle of the wrist (p. 105). But at rest there is also some extension; flexion and extension at the wrist joint are equal in range *from this rest position*. Thus *along the line of the radius* extension at the wrist joint has a wider range than flexion; consequently the articular surfaces of the three proximal carpal bones at the wrist joint extend further on their dorsal than on their ventral surfaces (Figs 2.66 and 2.68).

The four bones of the distal row are the trapezium, trapezoid, capitate and hamate. They articulate with the bones of the proximal row by an S-shaped **midcarpal joint**. At the midcarpal joint flexion is of greater range than extension, so that in the average western individual the metacarpus can be flexed to a right angle with the forearm but extended to only 45° with it. East of Suez the range of extension is much greater (observe the wrist and finger movements of both male and female Eastern dancers). The bones of each

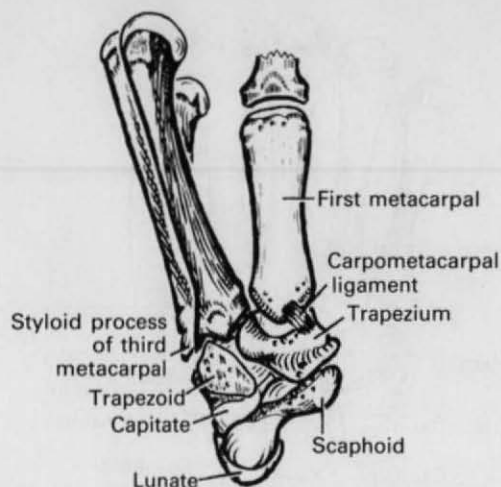


Fig. 2.69 Bones of the left carpus and metacarpus, from the radial side.

lies in the groove on the bone must not be damaged when manipulating the bone out.

The **trapezoid** lies wedged between trapezium and capitate, articulating proximally with the scaphoid and distally with the index-finger metacarpal. Its dorsal surface is four times the area of its ventral; both these non-articular surfaces are perforated by vessels.

The **capitate** is the largest of the carpal bones. It lies between the hamate medially and the trapezoid and scaphoid laterally. Proximally its convex surface fits the distal concavity of the lunate. Distally it articulates with the base of the middle and a tiny part of the ring-finger metacarpals. Anterior and posterior surfaces, non-articular, show many vascular foramina.

The **hamate**, alongside the capitate, makes with it a proximal convexity for the S-shaped midcarpal joint. The triquetrum articulates with this, while distally the fourth and fifth metacarpals have their own surfaces, conjoined. Broad dorsal and narrow medial surfaces are non-articular. The anterior surface, likewise non-articular, is projected as a hook-like flange that overhangs the ventral concavity of the carpus distal to the pisiform (Fig. 2.66).

METACARPUS

The thumb metacarpal is shorter and thicker than the others. Its base has a saddle-shaped facet for the trapezium. The convex facet on its head is not so boldly rounded as those of the other four metacarpals (Fig. 2.66); the flexor margin of the facet is grooved for the sesamoids of the thenar muscles. The shaft is set at

right angles to the plane of the other four (Fig. 2.67), so that its flexor surface faces across the palm. This surface has a rounded longitudinal ridge that divides it into two longitudinal concavities. The borders between flexor and extensor surfaces are sharp. The extensor surface is rather flat.

The remaining four metacarpals show expanded bases by which they articulate with the distal row of carpal bones and with each other. The middle metacarpal shows a prominent styloid process that projects dorsally into the angle between capitate and trapezoid. (Fig. 2.68). The shaft of each shows a ridge along its flexor surface. On the extensor surface is a long flat triangle with its base against the head and its apex prolonged proximally as a ridge which marks the shaft. The head carries a boldly rounded articular facet which extends farther on the flexor than the extensor surface. Adjacent surfaces of the heads are pitted by deep smooth fossae; behind these fossae lie dorsal tubercles, at the base of each triangular flat area of the shaft (Fig. 2.68). The four metacarpal bones together form a gentle concavity for the palm. Their heads form the knuckles of the fist; the four heads make a gentle convexity distally and also dorsally.

PHALANGES

Two phalanges form the thumb, three form each finger. Each of the five proximal phalanges has a concave facet on the base, for the head of its own metacarpal. Middle and distal phalanges carry a facet on each base that is divided by a central ridge into two concavities (Fig. 2.66). The heads of the proximal and middle phalanges are correspondingly trochlea-shaped, with their facets on the distal and flexor surfaces, not on the extensor surface. Each distal or terminal phalanx expands distally into a tuberosity, roughened on the flexor surface for attachment of the digital fibrofatty pad.

SESAMOID BONES

The pisiform is morphologically a sesamoid bone in the tendon of flexor carpi ulnaris, but it is rightly included in the carpus as a functional constituent of its bony skeleton. In the thumb a pair of sesamoid bones articulate with the flexor surface of the metacarpal head. That on the radial side lies in the radial tendon of flexor pollicis brevis, and that on the ulnar side in the fused tendons of adductor pollicis and flexor pollicis brevis. Sesamoid bones are commonly found also at the other metacarpal heads, especially the fifth and second, lodged in the palmar capsule of the metacarpophal-

langeal joints, and occasionally at the interphalangeal joints. Fibrocartilaginous at first, they ossify generally soon after puberty (see p. 10).

Ossification

Unlike the tarsus the carpus is all cartilaginous at birth. Each carpal bone ossifies from one centre. The largest bone, the capitate, ossifies first (first year) and the smallest, the pisiform, ossifies last (tenth year). The others ossify in sequence, according to their size, at approximately yearly intervals (hamate, triquetral, lunate, trapezium, scaphoid, trapezoid), so the whole carpus, except the sesamoid pisiform bone, is ossified by the seventh year. The shafts of all the metacarpals and phalanges ossify in utero, so that at birth there is a cartilaginous epiphysis at the base of every bone except the metacarpals of the palm (second, third, fourth and fifth), where the epiphysis is at the head. Note that the thumb metacarpal ossifies like a phalanx. The cartilaginous epiphyses ossify at the second to third year and fuse at 20 years. The tuberosity of each terminal phalanx ossifies in membrane.

ARTICULATED HAND

Returning now to the articulated hand, surface features can now be noted, together with the attachments of ligaments, tendons and muscles.

Surface features

Many of the bony features are visible or palpable in the living hand, and it is of far more use to be familiar with these landmarks than to study detailed osteology of the separate bones. On the flexor surface the tubercle of the scaphoid and the pisiform are visible in the fully extended wrist, and are palpable in the distal skin crease. The proximal skin crease (or the middle crease if three are present) marks the wrist joint (Fig. 2.70). The ridge of the trapezium and the hook of the hamate are each palpable deep to their overlying muscles. The prominence of the metacarpal heads can be felt in the palm; they lie along the distal skin crease of the palm, 2.5 cm proximal to the webs between the fingers. In the snuffbox, distal to the radial styloid, the scaphoid and trapezium can be felt, and the tubercle on the base of the thumb metacarpal is very prominent. The lunate, too deep to be readily felt on the flexor surface, is easily palpable midway between radial and ulnar styloids on the extensor surface; it rolls prominently under the palpating fingertip during full flexion of the wrist. The styloid process of the middle metacarpal is very promi-

nent in a line distal to the dorsal radial tubercle. It can often be seen.

Ligaments

The capsule of the wrist joint is attached to the articular margins of scaphoid, lunate and triquetral. At the radiocarpal joint very strong ligaments unite the lower end of the radius to the flexor surfaces of scaphoid and lunate distal to the capsule. On the extensor side strong bands connect the distal end of the radius to a smooth ridge on the triquetral; these are continuous with the bands of the radioulnar fibrocartilage. The carpal bones are themselves united by interosseous ligaments, and the deep concavity of the carpus is further maintained by the transverse fibres of the flexor retinaculum, which acts as a tie-beam. The retinaculum is attached to the pisiform and hook of the hamate, and to the tubercle of the scaphoid and ridge of the trapezium. The extensor retinaculum passes obliquely down from the radius to the pisiform and triquetral. The capsule of the carpometacarpal joint of the thumb is greatly strengthened by a ligament that passes obliquely from the tubercle on the trapezium to the dorsal prolongation of the base of the metacarpal bone (Fig. 2.69). Strong pisohamate and pisometacarpal ligaments connect the pisiform to the hook of the hamate and to the base of the fifth metacarpal. The other carpometacarpal joints are reinforced by strong anterior and posterior and interosseous ligaments, so that the synovial joints are almost immobile, especially in the case of the index- and middle-finger metacarpals.

The metacarpal heads of the palm (second to fifth) are united by the deep transverse ligament of the palm (p. 117). This is attached across the front of the palmar ligaments, which are thick bands of dense fibrous tissue attached to pits at the metacarpal heads and to the bases of the proximal phalanges. These ligaments show grooves for the flexor tendons, and may hold sesamoid bones. Collateral ligaments stabilize the metacarpophalangeal joints; they are attached to the pits and dorsal tubercles at the sides of the metacarpal heads and to the smooth facets at the sides of the bases of the proximal phalanges. Interphalangeal ligaments form similar collateral bands (Fig. 2.56). The fibrous flexor sheaths bridge the grooves in the palmar ligament; each is then attached along the sharp margin of proximal and middle phalanges and surrounds the insertion of the profundus tendon on the terminal phalanx. Distal slips of the palmar aponeurosis are attached not only to the fibrous flexor sheaths but also to the bases and along the sides of the proximal phalanges.

No palmar aponeurosis extension reaches the thumb,

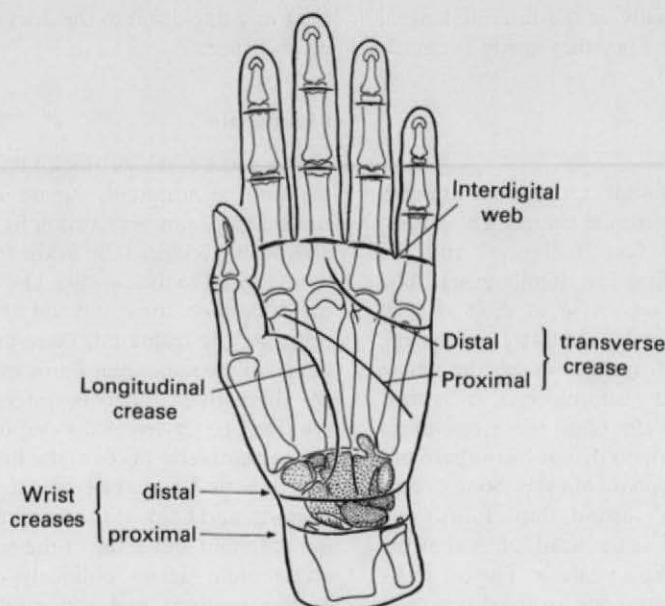


Fig. 2.70 Surface projections of some bony features of the left wrist and hand and skin creases. The proximal wrist crease indicates the level of the wrist joint. The metacarpophalangeal joints are far proximal to the interdigital webs.

but the two phalanges give attachment to a fibrous flexor sheath for the tendon of flexor pollicis longus.

Tendons

The tendons of forearm muscles are those of the wrist and digits. The flexor carpi radialis lies in the groove beside the ridge of the trapezium, being held there by a band uniting the ridge with the capitate. It then passes on to tubercles at the bases of the second and third metacarpals. It sometimes gives a slip to the tubercle of the scaphoid. Flexor carpi ulnaris is received into the pisiform, whence pisohamate and pisometacarpal ligaments prolong the insertion of the muscle. Flexor digitorum profundus is received into the proximal part of the base of the terminal phalanx of each finger; flexor pollicis longus is attached similarly to the terminal phalanx of the thumb. Flexor digitorum superficialis beyond its chiasma is inserted by two slips alongside the sharp borders of each middle phalanx.

Extensor carpi ulnaris is attached to a smooth-surfaced tubercle at the base of the fifth metacarpal. Extensor carpi radialis brevis is received into the styloid process of the middle metacarpal and the surface of bone distal to this. Extensor carpi radialis longus has an

attachment to the base of the index-finger metacarpal. The long extensors of the fingers spread into the extensor expansions (p. 108). All four receive also the interossei and lumbricals. The index finger expansion receives extensor indicis and the little finger extensor digiti minimi as well. The extensor digitorum tendon is inserted partly into the base of the proximal phalanx, completing here the dorsal capsule of the metacarpophalangeal joint, and then runs on to divide into a central slip for the base of the middle phalanx and two marginal slips that unite to be inserted into the base of the terminal phalanx.

The thumb receives a tendon into the base of each of its three bones (Fig. 2.42). That of the metacarpal is abductor pollicis longus; it is inserted to the front of the tubercle, at the junction of lateral and anterior margins of the base. The extensor pollicis brevis tendon runs with it, but passes on across the flat dorsal surface of the metacarpal to reach the base of the proximal phalanx. The extensor pollicis longus tendon passes separately across the wrist to reach the base of the terminal phalanx; this tendon is stabilized across the metacarpophalangeal joint by expansions from the abductor pollicis brevis and adductor pollicis. There is no extensor expansion on the thumb.

The tendons of the intrinsic muscles are best studied with the muscles themselves.

Muscles

No muscles, only tendons, cross the wrist. All muscle fibres in the hand belong to intrinsic muscles, i.e. having both origin and insertion in the hand.

The three muscles of the thenar eminence arise from the radial side of the flexor retinaculum. Abductor pollicis brevis has a few fibres coming from the tubercle of the scaphoid and the crest of the trapezium. Flexor brevis and opponens pollicis arise also partly from the crest of the trapezium. The deeply lying opponens is inserted into the ridge along the radial border of the thumb metacarpal and into the longitudinal groove alongside this. Abductor brevis and flexor brevis are inserted together into the base of the proximal phalanx, on its radial side; a sesamoid bone usually lies in the tendon of the short flexor. Adductor pollicis arises deep in the palm. The large transverse head arises from the ridge along the palmar surface of the shaft of the middle metacarpal. The oblique head arises from the bases of the second and third metacarpals distal to the insertion of flexor carpi radialis and also from the adjoining capitate. The two bellies converge across the web of the thumb to the base of the proximal phalanx on its index-finger side; a sesamoid bone commonly lies in the tendon of the oblique head.

Of the hypothenar muscles, abductor digiti minimi arises from the tendon of flexor carpi ulnaris and the

pisometacarpal ligament, while the short flexor and opponens both arise from the flexor retinaculum and hook of the hamate. The deep branch of the ulnar nerve passes between the abductor and flexor before running beneath the opponens before crossing the hook of the hamate. Opponens digiti minimi is inserted into the palmar surface of the fifth metacarpal alongside the ulnar border of the shaft. The other two muscles are inserted into the base of the proximal phalanx distal to the attachment of the collateral ligament, on the ulnar margin.

The interossei arise from the shafts of the metacarpals. The palmar interossei are relatively small, and the first is sometimes absent. They arise from the flexor surface of their own metacarpal, from the groove that faces towards the middle metacarpal (they are adductors of the fingers towards the middle finger). The dorsal interossei arise from both bones that enclose their interosseous space. They are attached to the longitudinal grooves on the *flexor* surfaces of the shafts and extend around to the dorsal surface up to the margin of the flat triangle and proximal ridge already noted. The flat triangles proximal to the metacarpal heads are bare bone, and the extensor tendons play across these areas. The interossei are inserted chiefly into the extensor expansions, but some of the fibres of both palmar and dorsal tendons are received into the base of the proximal phalanx.

3. Lower limb

GENERAL PLAN

The human lower limb is built for support and propulsion. The two hip bones (pelvic girdle, p. 53) articulate with one another in front at the pubic symphysis, and each is firmly fixed to the lateral part of the sacrum by the relatively immobile sacroiliac joint. The rigid bony pelvis thus produced transmits the body weight through the acetabulum of the hip bone to the lower limb and likewise transmits the propulsive thrust of the lower limb to the hip bone. In sitting, body weight is transmitted to the ischial tuberosities and the legs are free to rest.

The fixation of the hip bones restricts movements in the hip region compared with the shoulder, but a wide range of flexion-extension movements and a lesser degree of abduction-adduction are still possible. At the knee and ankle flexion and extension are the essential movements (although there are some rotatory complications at the knee), while in the foot there are limited movements at small joints which are adapted for flexible rigidity coupled with propulsive requirements.

Although the lower limb is commonly called the leg, this term strictly refers to the region between knee and foot. Above the knee is the thigh, which can be divided into three compartments — anterior or extensor, medial or adductor, and posterior or flexor. (Note that the terms extensor and flexor are used here in their morphological sense; because of the way the limb rotates medially during development, the original dorsal or extensor surface becomes anterior, and the ventral or flexor surface becomes posterior.) The gluteal region or buttock lies behind the pelvis and hip, above the posterior compartment of the thigh. The leg proper also has three compartments — anterior or extensor, lateral or peroneal, and posterior or flexor (calf). The foot has a dorsum or upper surface and a sole or plantar surface.

PART 1

ANTERIOR COMPARTMENT OF THE THIGH

Subcutaneous tissue

The fat of the front of the thigh contains cutaneous nerves, lymphatic vessels and nodes, the termination and tributaries of the great saphenous vein and cutaneous branches of the femoral artery. The membranous layer of the superficial fascia of the anterior abdominal wall (Scarpa's fascia, p. 241) extends into the upper part of the thigh just below the inguinal ligament.

SUPERFICIAL NERVES

The cutaneous branches of the lumbar plexus that supply the thigh are derived from the first three lumbar nerves. They are the ilioinguinal, femoral branch of the genitofemoral and the medial, intermediate and lateral femoral cutaneous nerves (Fig. 3.52). In addition the superficial branch of the obturator nerve supplies an area of skin above the medial side of the knee. All these nerves supply fascia lata as well as skin. The dermatomes of the lower limb are illustrated on page 24.

The **ilioinguinal nerve** is the collateral branch of the iliohypogastric, both being derived from the first lumbar nerve. It has no lateral but only a terminal cutaneous distribution. In the anterior abdominal wall it lies in the neurovascular plane between the internal oblique and transversus abdominis muscles, pierces internal oblique and supplies its lower fibres, and passes down beneath the external oblique (Fig. 5.9, p. 302) to emerge on the front of the cord through the superficial inguinal ring. Piercing the external spermatic fascia its chief distribution is to the skin of the root of the penis and the anterior one-third of the scrotum, but it

supplies also a small area of thigh below the medial end of the inguinal ligament.

The **genitofemoral nerve** is derived from the first and second lumbar nerves, but fibres from only L1 pass into the *femoral branch*. This branch is given off from the nerve as it lies on *psoas major* (or minor if this is present). It runs down on the external iliac artery and passes beneath the inguinal ligament into the femoral sheath. It pierces the anterior wall of the sheath and the overlying fascia lata below the middle of the inguinal ligament (Fig. 3.1). It supplies most of the skin over the femoral triangle. The femoral branch thus described is wholly cutaneous in its distribution. The genital branch enters the spermatic cord (p. 305) and does not reach the skin.

The **medial femoral cutaneous nerve** is a branch of the anterior division of the femoral nerve (L2, 3). Inclining medially across the femoral vessels it pierces the deep fascia (fascia lata) above the upper border of sartorius which, on the medial side of the thigh, is well below the inguinal ligament. It supplies the medial side of the thigh, and its terminal twigs join the patellar plexus (see below).

The **intermediate femoral cutaneous nerve** (L2, 3) has a common origin with the medial cutaneous nerve from the anterior division of the femoral nerve. It passes vertically downwards beneath the fascia lata, usually pierces the upper border of sartorius, and then pierces the fascia lata at a higher level than the medial cutaneous nerve to supply the front of the thigh as far down as the knee, where its terminal twigs join the patellar plexus.

The **lateral femoral cutaneous nerve** is a branch of the lumbar plexus (L2, 3). Passing from the lateral border of *psoas major* across the iliac fossa it lies at first behind the fascia iliaca; but approaching the inguinal ligament it inclines forwards and is incorporated within the substance of the iliac fascia, which is here a thick tough membrane. The nerve now passes behind or pierces the inguinal ligament, where it lies free in a fibrous tunnel a centimetre to the medial side of the anterior superior iliac spine (Fig. 3.1A).

The nerve enters the thigh deep to the fascia lata, and divides into anterior and posterior branches which pierce the fascia lata separately an inch or two below the lateral end of the inguinal ligament. The anterior branch contains all the L3 fibres of the nerve, and is distributed along the anterolateral surface of the thigh, and its terminal twigs enter the patellar plexus. The posterior branches, containing only L2 fibres, pass down the thigh along the posterolateral aspect (along the iliotibial tract).

The nerve is sometimes compressed as it passes through the inguinal ligament or where it pierces the

fascia lata, causing pain in the lateral side of the thigh (*meralgia paraesthetica*). In those individuals in whom fibres of *transversus abdominis* arise from the iliac fascia, freeing the nerve from its 'tunnel' in the inguinal ligament may not be enough to cure the pain; the nerve must also be freed from the iliac fascia, to prevent irritation from the pull of the contracting fibres of *transversus*.

The **obturator nerve** (L2, 3, 4) sends a twig from its superficial division into the subsartorial plexus, whence cutaneous branches pass to skin and fascia lata over the adductor magnus tendon above the medial condyle of the femur (Fig. 3.53). Direct branches from the superficial division of the obturator nerve frequently supply the skin on the medial side of the thigh above this level (Fig. 3.52).

Patellar plexus

This is a fine network of communicating twigs in the subcutaneous tissue over and around the patella and patellar ligament. It is formed by the terminal branches of the medial and intermediate femoral cutaneous nerves, of the anterior branch of the lateral femoral cutaneous nerve, and of the infrapatellar branch of the saphenous nerve (p. 185).

SUPERFICIAL ARTERIES

Four cutaneous branches of the femoral artery are found in the subcutaneous tissue below inguinal ligament.

The **superficial circumflex iliac artery** pierces the fascia lata lateral to the saphenous opening and passes up below the inguinal ligament to the anastomosis at the anterior superior iliac spine.

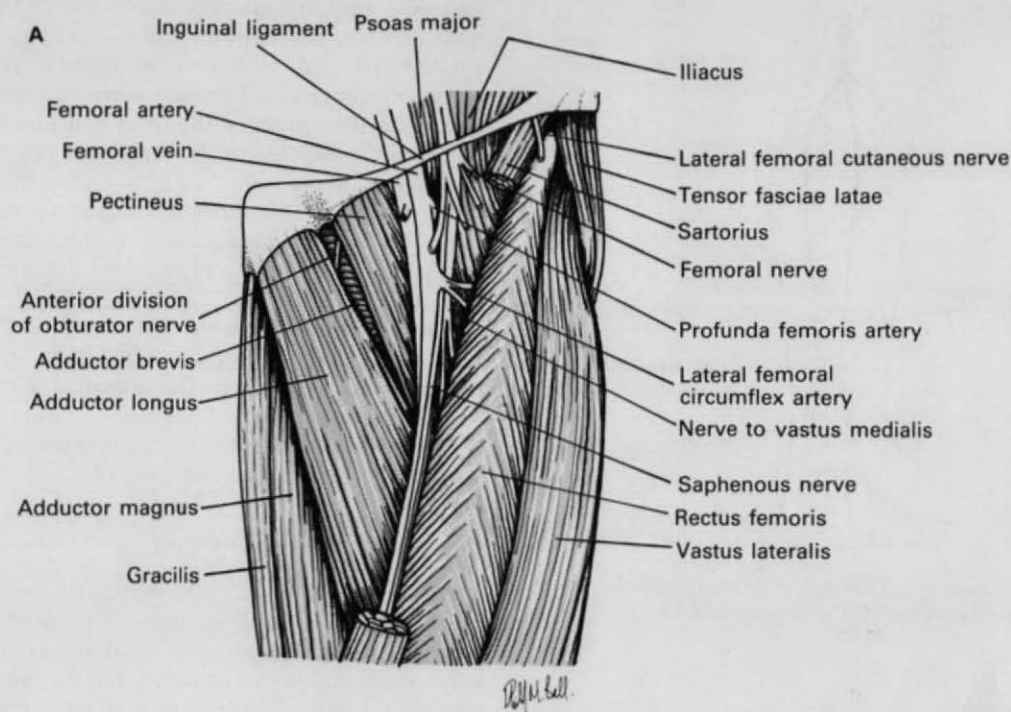
The **superficial epigastric artery** may pierce the fascia lata or emerge through the saphenous opening. It crosses the inguinal ligament and is distributed towards the umbilicus to the skin and fat of the lower abdominal wall.

The **superficial external pudendal artery** emerges from the saphenous opening and passes medially, in front of the spermatic cord (round ligament) to supply skin and superficial tissue of the scrotum (labium majus).

The **deep external pudendal artery** emerges more medially and passes behind the spermatic cord (round ligament) to supply the skin of the scrotum (labium majus).

SUPERFICIAL VEINS

These are essentially tributaries of the great (long) saphenous vein, one of the most important veins in the



body in view of the prevalence of varicosities developing at its lower end.

The **great saphenous vein**, the longest vein in the body, begins as the upward continuation of the medial marginal vein of the foot (p. 189). It courses upwards in front of the medial malleolus (Fig. 3.2), crosses the lower quarter of the medial surface of the tibia obliquely and runs up behind the medial border of the tibia towards the knee, where it lies a handbreadth behind the medial border of the patella — an important *surface marking*. It spirals forwards round the medial convexity of the thigh and ends by passing through the cribriform fascia covering the saphenous opening (Fig. 3.3) which lies 3.5 cm below and lateral to the pubic tubercle — an even more important surface marking. Here it joins the anteromedial side of the femoral vein. It contains up to 20 valves, more of them below knee level than above.

A number of tributaries may be expected to join the great saphenous vein in the region of the saphenous opening; like venous patterns elsewhere the exact number is variable since some may unite with others to form common trunks or may be missing. There are usually four veins that correspond to the four cutaneous branches of the femoral artery (superficial circumflex iliac, superficial epigastric, and superficial and deep

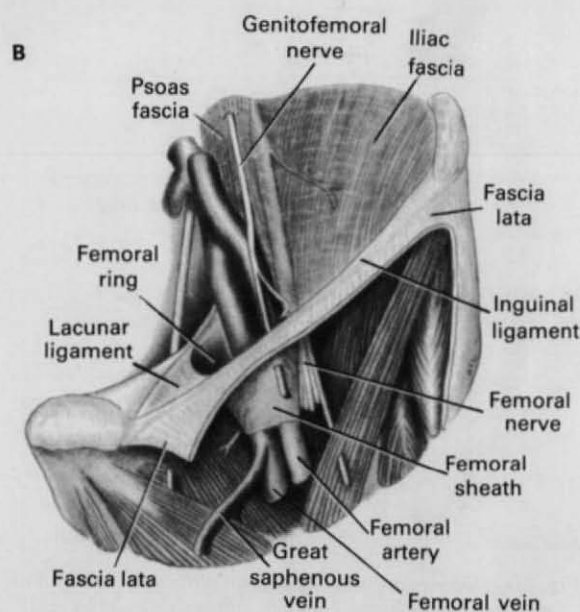


Fig. 3.1 Left inguinal and femoral regions. **A** Muscles, vessels and nerves, with fascia and part of sartorius removed to show the femoral artery and vein, saphenous nerve and the nerve to vastus medialis in the adductor canal. **B** The femoral ring and canal. The femoral canal, vein, artery and nerve emerge from beneath the inguinal ligament in that order from medial to lateral. The canal, vein and artery are within the femoral sheath, but the nerve is outside it.

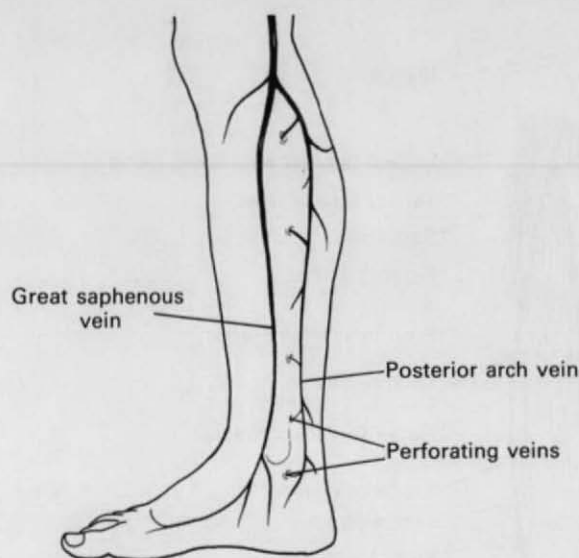


Fig. 3.2 Lower end of the right great saphenous vein, passing upwards in front of the medial malleolus.

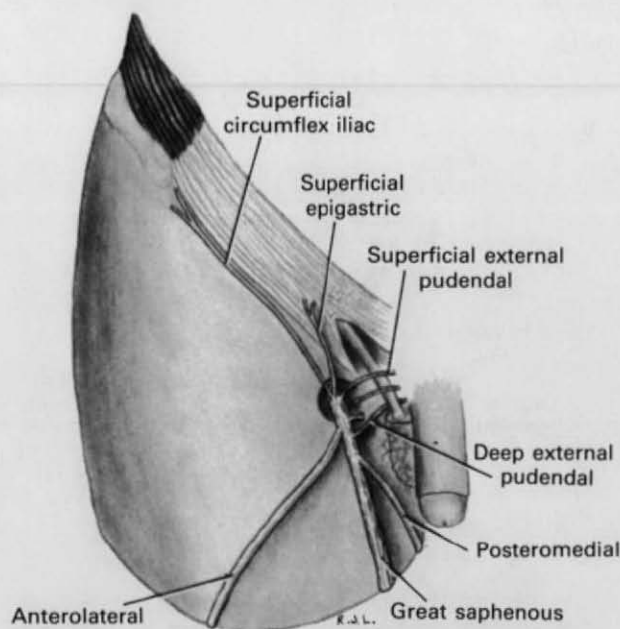


Fig. 3.3 Upper end of the right great saphenous vein and its tributaries. The saphenous opening, through which the vein passes to join the femoral vein, lies 3.5 cm below and lateral to the pubic tubercle.

external pudendal), and in addition there may be a deep vein that pierces the fascia lata over adductor longus. The superficial external pudendal artery runs horizontally between the superficial and deep external

pudendal veins; the artery is usually behind the saphenous vein but may lie in front of it. There may also be anterolateral and posteromedial femoral veins (the latter sometimes called the accessory saphenous vein) that drain wide areas of the thigh and join the great saphenous a little below the saphenous opening. The fact that the upper end of the great saphenous vein has these numerous tributaries converging upon it is an important feature distinguishing it from the femoral vein which at this level only receives the great saphenous itself (p. 155).

The superficial epigastric vein may form the lower end of the thoracoepigastric vein which serves as a communication between the superior and inferior venae cavae (p. 241).

For the deep connexions of the lower end of the great saphenous vein in the leg, see page 185.

LYMPH NODES AND VESSELS

Large lymphatic vessels accompany the great saphenous vein from the foot, leg and thigh (Fig. 3.4). Numerous large vessels also spiral around the outer side of the thigh to converge on the **superficial inguinal nodes**. These consist of up to 20 nodes arranged in an irregular T-shaped pattern in the subcutaneous fat of the femoral triangle. Inspection of the dissected nodes shows no obvious arrangement into groups yet they are rightly described as belonging to three groups, for they drain three distinct areas. The *vertical group*, lying lateral to the termination of the great saphenous vein, receives lymphatics from the deep fascia (and everything superficial to it) of the lower limb. The *lateral group*, lying below the lateral part of the inguinal ligament, receives lymph from the buttock, flank and back below the level of the waist. The *medial group* lies below the medial end of the inguinal ligament, and a node or two may encroach on the anterior abdominal wall. They receive from below the umbilicus and medial to a line drawn vertically upwards from the anterior superior iliac spine. More important, the medial group receives lymph also from the perineum; it is to be noted that the perineum includes the lower part of the anal canal, the urethra and the external genitalia of both sexes (*but excluding the testes*). The efferent lymphatics from all three groups converge towards the saphenous opening and pass through the cribriform fascia to enter the three or four **deep inguinal nodes**, lying medial to the femoral vein. Their passage through the fascia covering the saphenous opening produces a number of holes which give rise to the sieve-like appearance denoted by the name 'cribriform'.

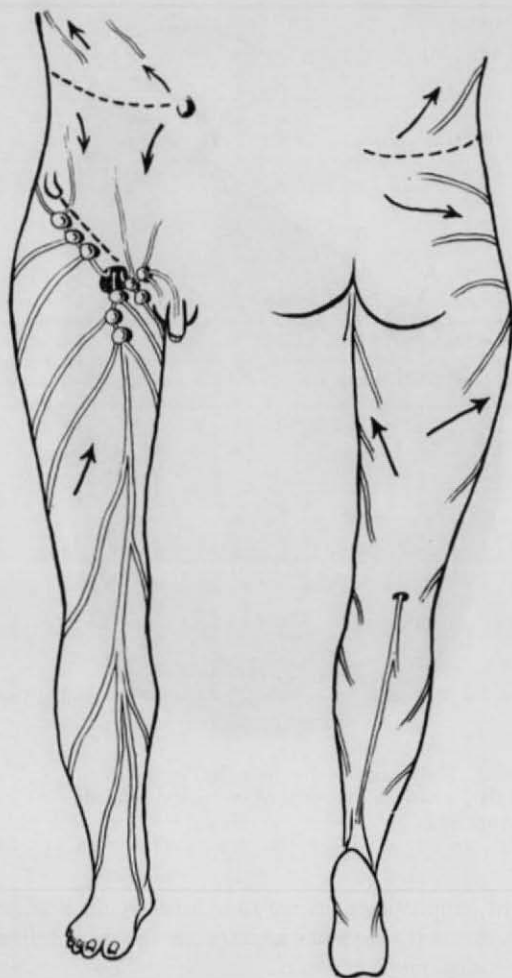


Fig. 3.4 Superficial lymph drainage of the right lower limb, front and back. The superficial inguinal nodes receive all the lymph from the subcutaneous tissues below the waist.

SUPERFICIAL FASCIA

The membranous layer of the superficial fascia of the abdominal wall (Scarpa's fascia) extends into the thigh and becomes fixed to the fascia lata (Fig. 3.5) at the flexure skin crease of the hip joint, where attachment of skin to fascia lata limits its further descent. The attachment extends laterally from the pubic tubercle but *below the inguinal ligament*. It should be noted that the saphenous opening lies below this line, so that a femoral hernia, emerging from the saphenous opening, can never come to lie in the space beneath Scarpa's fascia. The hernia emerges into ordinary subcutaneous fat and can therefore never become very large.

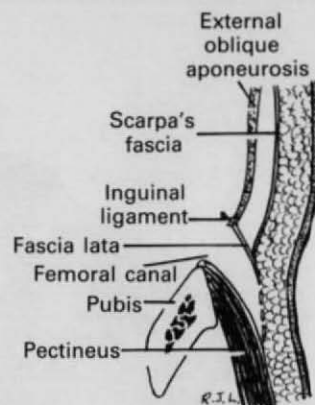


Fig. 3.5 Sagittal section through the femoral canal. The membranous layer of superficial fascia of the abdomen is attached to the fascia lata below the inguinal ligament but above the saphenous opening, so that a femoral hernia passing through the cribriform fascia at the opening is directed into the subcutaneous fat and not into the potential space deep to the abdominal fascia.

FASCIA LATA

The deep fascia, the **fascia lata** encloses the thigh, like a stocking but one whose top is too large. A vertical slit has been cut at the top of the stocking, so to speak, and the cut edges overlapped to fit the bony pelvis, so forming the margin of the saphenous opening described below. The fibres of the fascia lata lie vertically in the long axis of the thigh. Examine the hip bone or, better still, an articulated bony pelvis. Trace the attachments of the fascia lata to the pelvic girdle. The line encloses all the thigh and hamstring muscles.

Commence with the cut edge A in Figure 3.6 and attach it to the pubic tubercle. The top of the 'stocking' of fascia lata traced laterally is seen to be attached to the inguinal ligament, which it draws into a downward convexity when the thigh is extended. From the anterior superior iliac spine the top of the 'stocking' is attached to the external lip of the iliac crest, splitting to enclose the tensor fasciae latae muscle, as far back as the tubercle of the iliac crest. From the tubercle the single layer of fascia is attached to the iliac crest as far back as the posterior gluteal line, where it again splits to enclose gluteus maximus. The two layers that enclose the gluteus maximus are very thin indeed, but are nevertheless in continuity with the rest of the fascia lata. Attached to bone at the edges of the gluteus maximus origin on the ilium and sacrum, and to the sacrotuberous ligament, the fascia lata may now be traced along the convexity of the ischial tuberosity, the ischiopubic ramus and the body of the pubic bone,

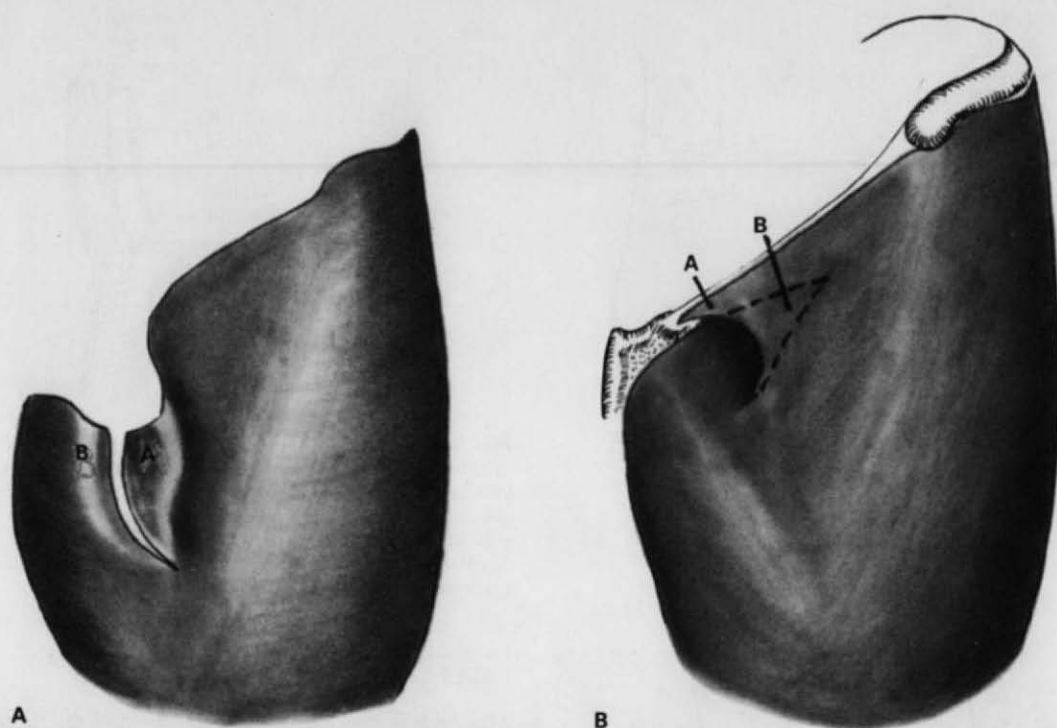


Fig. 3.6 Fascia lata and the formation of the left saphenous opening. The margin of the slit in the fascia at A (A) becomes attached to the pubic tubercle and inguinal ligament (B), while the edge at B (A) is tucked beneath A and attached to the pectineal line (B), so forming the saphenous opening.

between the attachments of the adductors and gracilis on the one hand and the perineal muscles on the other. Passing over the origin of adductor longus in the angle between pubic crest and symphysis the top of the 'stocking' is now attached to bone just below the pubic tubercle, and, further laterally, it passes beneath the pubic tubercle and inguinal ligament, lying on the surface of pectineus to be attached to the pectineal line as far laterally as the cut edge B (Fig. 3.6). The cut edge A thus appears as a crescentic or falciform margin to the **saphenous opening**, which is merely the oblique space lying between the cut edges of the top of the 'stocking'. The deep part of B lies on pectineus beneath the femoral sheath, and is prolonged downwards in front of the adductor muscles as the medial intermuscular septum. To change the simile, the edges of A and B of the slit in Figure 3.6 are overlapped like lapels of a double-breasted jacket and the great saphenous vein passes through the gap like a hand reaching into the inside pocket. The saphenous opening is covered in by a loose fascia attached laterally to the falciform edge and medially to the fascia lata where it lies over adductor longus. This fascia is pierced by the great saphenous vein and the

efferent lymphatics from the superficial inguinal lymph nodes, giving it a sieve-like appearance whence it derives the name of *cribriform fascia*.

The fascia lata is attached below to the patella and to the inferior margins of the tibial condyles and to the head of the fibula. Over the popliteal fossa it is strengthened by transverse fibres and continues below into the deep fascia of the calf. The fascia lata has been seen to enclose two muscles, the tensor fasciae latae and gluteus maximus. These two muscles converge towards each other below the greater trochanter of the femur. The *deep half of the lower half* of gluteus maximus (p. 162) is inserted into the gluteal crest of the femur but the remaining three-fourths are inserted with tensor fasciae latae into the iliotibial tract (see below). The triangular interval between them is filled by the continuation of the fascia lata described above, the whole constituting the 'deltoid of the hip joint' reminiscent of the deltoid muscle covering the shoulder joint.

Tensor fasciae latae

This arises from a 5-cm length of the external lip of the

iliac crest between the anterior superior iliac spine and the tubercle of the crest. It is a thin sheet of muscle at its origin; it is triangular in shape and becomes thicker at its insertion into the iliotibial tract. Its anterior border lies edge to edge with sartorius at the anterior superior iliac spine (Fig. 3.1), below which the two muscles diverge and allow rectus femoris to emerge between them.

Nerve supply. By the superior gluteal nerve (L4, 5, S1), which crosses the buttock and ends in the muscle.

Action. Its action is to pull upon the iliotibial tract, so assisting gluteus maximus in extending the knee joint (p. 163); in quadriceps paralysis the two muscles may act as weak (and incomplete) extensors of the knee. The muscle is also very active in helping to stabilize the pelvis during walking (p. 164).

Iliotibial tract

This is a thickening of the fascia lata that commences at the level of the greater trochanter, where three-quarters of gluteus maximus and the tensor fasciae latae are inserted into it. It passes vertically down the lateral aspect of the thigh, crosses the lateral condyle of the femur and is inserted into a smooth circular facet 1 cm in diameter on the anterior surface of the lateral condyle of the tibia (Fig. 3.33A). When the knee is straight the

tract passes in front of the axis of flexion; thus it maintains the knee in the hyperextended position. It is not an extensor of the flexed knee, however; in the right-angled knee it passes behind the axis of flexion. The lateral intermuscular septum in the lower part of the thigh is attached to the tract and the mass of vastus lateralis can be seen bulging in front of it (Fig. 3.7). The septum connects the tract to the linea aspera of the femur (p. 222). The tract is particularly in action when the slightly flexed knee is bearing the weight of the body, and is thus constantly in use in the appropriate phases of walking and running. In rising from the sitting position, gluteus maximus extends the hip and then, as the knee is extended by quadriceps, the tract operates to assist quadriceps (feel it on yourself or a friend).

When the tract is holding the knee in the hyperextended position, as when standing on one leg with the other knee slightly bent, the quadriceps is relaxed and the patella freely mobile. In this position, so commonly used when standing talking to someone, waiting in a queue, etc., the tract is taking over part of the duties of gluteus medius and minimus in resisting adduction at the hip (p. 164) and preventing the pelvis from tilting too far to the opposite side.

The **lateral intermuscular septum** is a strong layer extending into the thigh from the deep surface of the

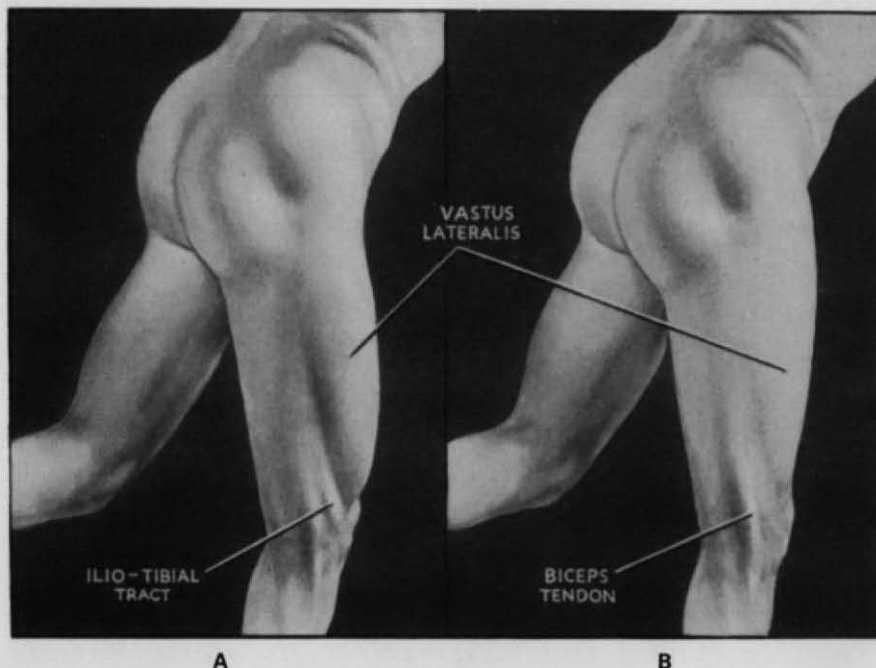


Fig. 3.7 Iliotibial tract. In **A** with the quadriceps muscle relaxed, the flaccid vastus lateralis bulges over the tract. In **B**, contraction of the quadriceps abolishes the groove made by the tract because vastus lateralis is now in firm contraction.

iliotibial tract. It is attached to the lateral lip of the linea aspera. From its upper end it passes backwards to the fascia lata, forming a *midline* septum between vastus lateralis and the origin of the hamstrings (Fig. 3.8). Its lower part lies more obliquely and is attached to the iliotibial tract. It prevents lateral movement of the tract, which forms therefore a gutter behind the bulging vastus lateralis (Fig. 3.7).

FEMORAL TRIANGLE

When the fascia lata is removed from the front of the thigh the underlying muscles are exposed (Fig. 3.1). The most superficial of all is sartorius, a parallel-sided ribbon of muscle that swings obliquely across the thigh. The adductor longus is prominent on the medial side, and the two muscles enclose, with the inguinal ligament, the femoral triangle.

The **femoral triangle** is defined as the triangle that lies between the inguinal ligament, the medial border of sartorius, and the *medial* border of adductor longus. The floor of the triangle is not flat, but gutter-shaped, and the hollow can be seen when the thigh is flexed. The femoral nerve and vessels lie in the gutter. The muscles lying in the floor of the femoral triangle are the iliacus, psoas,

pectineus and, in the narrow interval between pectineus and adductor longus, a glimpse is had of adductor brevis with the anterior division of the obturator nerve lying on it. All these muscles pass to the posterior aspect of the femur, hence the gutter shape of the floor of the triangle. The two adductors are described on page 159.

Sartorius

This muscle arises from the upper centimetre of the anterior border of the ilium, immediately beneath the anterior superior iliac spine. Its parallel fibres extend for the whole length of the muscle. It spirals obliquely across the thigh (Fig. 3.1), passes downwards on the fascial roof of the adductor canal, lies near the posterior aspect of the medial condyle of the femur, whence its tendon proceeds to be inserted into the upper end of the subcutaneous surface of the tibia, in front of gracilis and semitendinosus tendons and separated from them by a bursa. It is pierced usually by two nerves, the intermediate cutaneous nerve of the thigh below its origin and the infrapatellar branch of the saphenous nerve above its insertion. The saphenous nerve itself becomes cutaneous by piercing the fascia between sartorius and gracilis (p. 158).

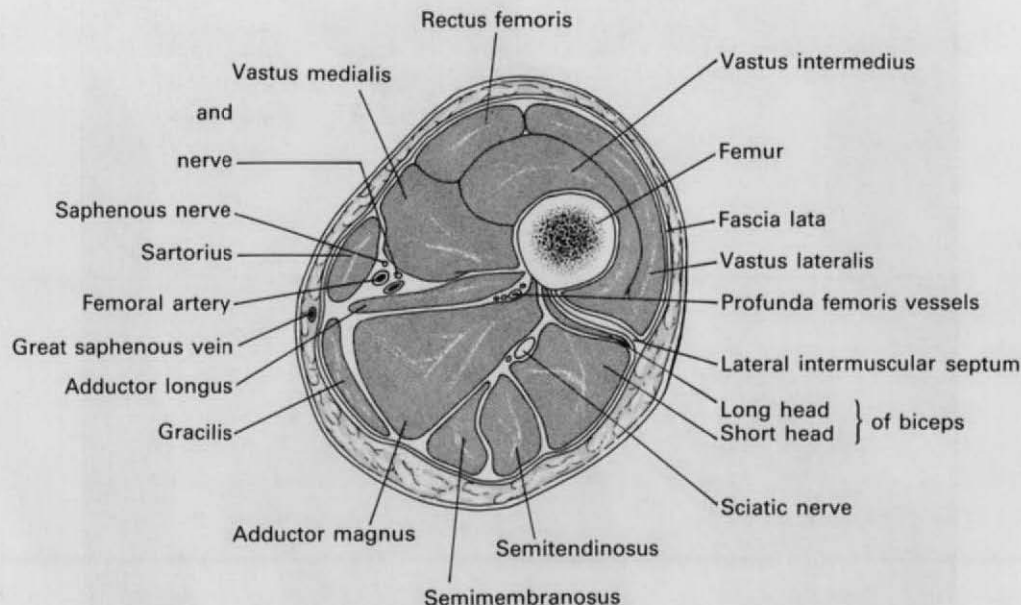


Fig. 3.8 Cross-section of the left upper thigh, looking towards the hip. The vasti embrace the femur, and the lateral intermuscular septum lies between vastus lateralis and biceps, so attaching the iliotibial tract to the linea aspera of the femur. The sciatic nerve is surrounded by the hamstrings, and the femoral vessels are in the triangular adductor canal in front of adductor longus, with the profunda vessels behind adductor longus adjacent to the femur.

Nerve supply. By a branch from the anterior division of the femoral nerve (L2, 3, 4).

Action. To draw the lower limb into the sitting tailor's position (thigh flexed and laterally rotated, knee flexed). It is difficult to understand the need for this muscle in man, since much stronger thigh and knee flexors exist. Perhaps its purpose is to act as a guy rope on the pelvis (see p. 185).

Adductor longus is described with the other adductors on page 159.

Iliacus

This muscle arises from the hollow of the iliac fossa (p. 358). Entering the thigh beneath the lateral part of the inguinal ligament, where the femoral nerve lies on it, it curves backwards behind the femoral vessels to be inserted into the front of the psoas tendon and a small area of femoral shaft just below the lesser trochanter. The lower part of the iliac fossa is bare of muscle, the concave gap being occupied by a bursa the size of the hollow of the palm. This is called the *iliac bursa*, and it may communicate through a gap in the capsule with the cavity of the hip joint. It was formerly misnamed the psoas bursa.

Nerve supply. By the femoral nerve (L2, 3) in the iliac fossa.

Action. With psoas, it is a powerful flexor of the hip joint (p. 168).

Psoas major

This arises from the lumbar spine (p. 356). It passes into the thigh below the middle of the inguinal ligament, at which level the femoral artery lies on it. Its rounded tendon is inserted into the lesser trochanter (Figs 3.9 and 3.10). The *iliac bursa* extends deep to psoas and passes forwards somewhat between the two muscles, whose unequal lengths cause intermuscular gliding here. Both iliacus and psoas pass across the front of the capsule of the hip joint, with the lower part of the bursa lying between. The bursa may communicate with the hip joint through a gap in the capsule that lies between the iliofemoral and pubofemoral ligaments (Fig. 3.18).

Nerve supply. By the first three lumbar nerves (mainly L2).

Action. With iliacus it is a powerful flexor of the hip (pp. 168 and 358).

The common insertion of the two muscles and the similarities of their actions result in the combined mass being often referred to as the 'iliopsoas', but the term is inaccurate and has nothing to recommend it except economy of expression. Psoas is supplied segmentally

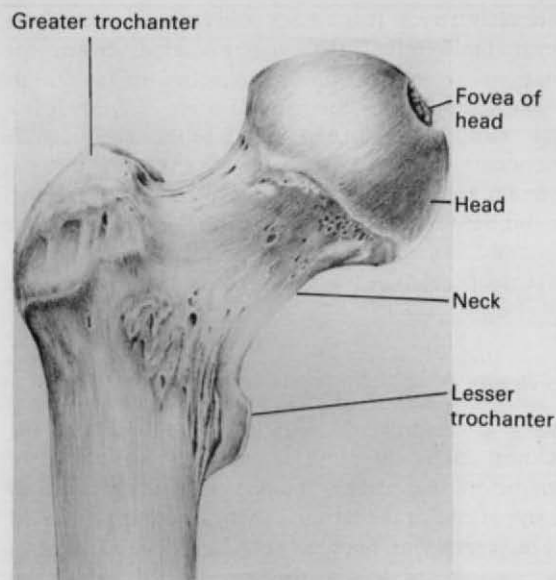


Fig. 3.9 Upper end of the right femur, from the front. The rough ridge between the two trochanters is the intertrochanteric line.

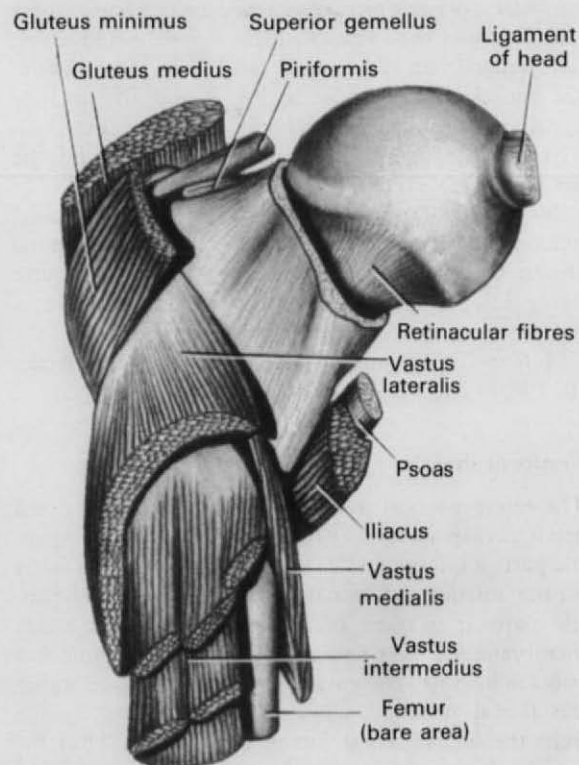


Fig. 3.10 Attachments at the upper end of the right femur, from the front.

by lumbar nerves. It is a body-wall muscle, part of the prevertebral rectus, that has migrated down, for functional reasons, to become attached to the femur. Iliacus is supplied by the femoral nerve (L2, 3). It is a thigh muscle that has migrated up to the iliac fossa for functional reasons. Both psoas and iliacus share a common action on the hip joint, but psoas flexes also the lumbar vertebrae, while iliacus does not. The term 'iliopsoas' is permissible only when referring to the movements produced at the hip joint (flexion by both muscles).

Pectineus

This is a quadrilateral muscle that arises from the pectineal line of the pubis and from a narrow area of bone below (Fig. 3.13). It slopes backwards down to the upper end of the femoral shaft, where it is inserted into a vertical line between the spiral line and gluteal crest, below the lesser trochanter (Fig. 3.15). The muscle is covered anteriorly by an infolding of fascia lata that passes beneath the falciform margin of the saphenous opening (B in Fig. 3.6) and is continued below as a thin sheet of areolar tissue, the *medial inter-muscular septum*, which is attached to the linea aspera and separates the vastus medialis from the adductors. The femoral vein and femoral canal lie on the surface of the muscle, while adductor brevis and the anterior division of the obturator nerve lie behind it (Fig. 3.1). The muscle and its relations are worthy of note; it is the key to the femoral triangle.

Nerve supply. By the anterior division of the femoral nerve (L2, 3) by a branch that passes behind the femoral sheath. Occasionally it receives a twig from the obturator nerve (L2, 3), indicating its double origin in such cases from flexor and extensor compartments (p. 22).

Action. To flex, adduct and *medially* rotate the femur (p. 168).

Femoral sheath

The extraperitoneal areolar tissue of the abdominal and pelvic cavities varies very much in density. Over expansile parts it is loose and cellular (e.g. transversalis fascia on the anterior abdominal wall) while over nonexpansile parts it is often condensed into a thick tough membrane (e.g. iliac fascia). The aorta and its branches and the inferior vena cava and its tributaries lie within this fascial envelope, while the spinal nerves emerge from the intervertebral foramina behind it. Thus the vessels that emerge from the abdominal cavity into the thigh must pierce the fascial envelope, while the femoral nerve does not do so.

The femoral vessels, passing beneath the inguinal ligament, draw around themselves a funnel-shaped prolongation of the extraperitoneal fascia derived from the transversalis fascia in front and the psoas fascia behind (Fig. 3.1). This prolongation of fascia, the femoral sheath, fuses with the adventitia of the artery and vein about an inch below the inguinal ligament. The presence of the sheath allows freedom for the femoral vessels to glide in and out beneath the inguinal ligament during movements of the hip joint. The sheath does not protrude into the thigh in the fetal position of full flexion, but is drawn down below the inguinal ligament in the adult position of extension of the thigh.

The femoral nerve in the iliac fossa lies in the gutter between psoas and iliacus, behind the fascia iliaca. Lateral to the femoral sheath the transversalis fascia and fascia iliaca fuse with inguinal ligament, and the femoral nerve thus enters the thigh *outside* the femoral sheath. The sheath itself is separated from the medial side of the femoral vein by a space, the **femoral canal** (Fig. 3.1), that serves two purposes. Firstly, it is the route by which the efferent lymph vessels from the deep inguinal nodes pass to the abdomen and secondly it provides a loose 'dead space' into which the femoral vein can expand during times of increased venous return from the lower limb. The femoral canal is widest at its abdominal end, where its opening, the **femoral ring**, has four boundaries. Anteriorly lies the medial part of the inguinal ligament, medially the crescentic edge of the lacunar ligament (or iliopubic tract—p. 299), posteriorly the pectineal ligament and pectineus, while laterally lies the femoral vein. A femoral hernia enters the femoral canal through this ring. The lacunar ligament may have to be incised to release a strangulated hernia, and here an accessory (abnormal) obturator artery is at risk (p. 396). The canal contains a lymph node (of Cloquet) which in the female is said to drain directly from the clitoris, and in the male from the glans penis.

The anterior wall of the femoral sheath is pierced by the femoral branch (L1) of the genitofemoral nerve, which runs on the anterior surface of the external iliac artery into the sheath (Fig. 3.1).

Femoral artery

The artery enters the thigh at a point midway between the anterior superior iliac spine and the pubic symphysis (midinguinal point) just medial to the deep inguinal ring, which lies above the midpoint of the inguinal ligament. Here it lies on the psoas major tendon, which separates the artery from the capsule of the hip joint, and this is the position where its pulsation

can be felt or where it can be entered for arterial catheterization. It emerges from the femoral sheath and courses downwards to disappear beneath sartorius where the muscle crosses the lateral border of adductor longus and enters the adductor canal. It has four small branches below the inguinal ligament (p. 146) and just below the termination of the femoral sheath gives off a large branch, the profunda femoris, the chief artery of the thigh.

The *surface marking* of the femoral artery, with the hip slightly flexed and laterally rotated, is from the midpoint between the pubic symphysis and the anterior superior iliac spine, along the upper two-thirds of a line towards the adductor tubercle. To expose the artery in the adductor canal sartorius is retracted backwards.

Cannulation. The femoral artery is second only to the radial (p. 93) as the site of choice for the placement of an arterial line. Its superficial position below the inguinal ligament makes it easily accessible. The commonest complications include retroperitoneal haemorrhage and perforation of the gut (by entering the abdominal cavity) and arteriovenous fistula (with the femoral or external iliac vein).

The **profunda femoris artery** is normally the vessel of supply for all thigh muscles (unless its circumflex branches come directly from the femoral — see below). It arises from the lateral side of the femoral artery about 4 cm ($1\frac{1}{2}$ in) below the inguinal ligament and then spirals deep to it, continuing down deep to adductor longus (p. 159), whose upper border separates the femoral and profunda arteries (adductor brevis separates the anterior and posterior divisions of the obturator nerve, p. 161). The profunda vein lies in front of the profunda artery, which continues down on adductor magnus very near the linea aspera and ends as the fourth perforating artery (described below with the other three). Apart from numerous muscular branches it gives off large lateral and medial circumflex femoral vessels.

The **lateral circumflex femoral artery** arises from the lateral side of the profunda artery or separately from the femoral artery (Fig. 3.1A), and passes laterally, keeping as *near the femur* as neighbouring muscles will allow. It passes between the many branches of the femoral nerve, dividing them for descriptive purposes into superficial and deep groups, and disappears from the femoral triangle beneath sartorius to lie deep to rectus femoris. Here it breaks up into three branches.

The *ascending branch* runs up on the vastus lateralis, under cover of sartorius and tensor fasciae latae. It gives a branch to the trochanteric anastomosis and passes on towards the anterior superior iliac spine, where it ends by anastomosing with the superficial and deep

circumflex iliac, an iliac branch of the iliolumbar and the superior branch of the superior gluteal artery. This ascending branch is a large vessel and in the anterior approach to the hip joint between sartorius and tensor fasciae latae, it and its venae comitantes must be secured when separating the muscles.

The *transverse branch* passes across the vastus lateralis and winds around the femur to form one limb of the cruciate anastomosis (p. 166).

The *descending branch* slopes steeply downwards, with the nerve to vastus lateralis, in a groove between the anterior edge of the vastus lateralis and the vastus intermedius. It supplies both muscles and ends by sending twigs to the anastomosis around the lower end of the femur.

The **medial circumflex femoral artery** arises from the medial side of the profunda (occasionally from the femoral) very near its lateral companion and immediately passes backwards between pectineus and the psoas tendon. Running above the upper border of adductor brevis, it passes between the contiguous borders of quadratus femoris and adductor magnus to enter the gluteal region. It gives branches to adjacent muscles and ends by dividing on quadratus femoris into ascending and horizontal branches which run along the upper and lower borders of the muscle. The *ascending branch* follows obturator externus to the trochanteric anastomosis, while the *horizontal branch* forms the medial limb of the cruciate anastomosis (p. 166).

The four **perforating arteries** pass backwards through the adductor muscles near the linea aspera, the first above and the fourth below adductor brevis, and the second and third through it. They supply the adductor muscles and the hamstrings and end in vastus lateralis. The terminal twigs make a series of anastomoses with one another, with the cruciate anastomosis above and with the popliteal artery below.

Femoral vein

The vein enters the lower angle of the femoral triangle, where it lies posterior to the artery. In its course through the femoral triangle it ascends posteriorly and comes to lie on the medial side of the artery at the lower limit of the femoral sheath. It receives a tributary corresponding to the profunda femoris artery and just below the femoral sheath the great saphenous vein joins its anteromedial side (Fig. 3.1). Within the sheath it passes under the inguinal ligament and runs along the brim of the pelvis as the external iliac vein. It has valves just above the junctions with the profunda and great saphenous veins.

In the living body the position of the femoral vein below the inguinal ligament is found by feeling the

pulsations of the femoral artery, which is immediately lateral to the vein. The vein is distinguished from the great saphenous vein by the fact that, unlike the saphenous, it has no tributaries at this level apart from the saphenous itself. In thin people the femoral vein may be surprisingly near the surface even though it is within the femoral sheath, and in varicose vein operations it is obviously vital to identify the saphenous vein correctly and not tie off the femoral by mistake.

Femoral nerve

This is the nerve of the extensor compartment of the thigh, and is formed from the *posterior* divisions of the anterior rami of the lumbar nerves 2, 3 and 4, the same segments as the obturator nerve, but the adductor muscles are derived from the flexor muscles of the thigh, so their nerve is derived from *anterior* divisions of those rami (p. 21). Lying in the iliac fossa between psoas and iliacus the femoral nerve enters the thigh by passing deep to the inguinal ligament at the lateral edge of the femoral sheath, which separates it from the femoral artery (Fig. 3.1). After an inch or so it breaks up into a number of branches, through which passes the lateral circumflex femoral artery, separating the branches into superficial and deep.

The **superficial group** consists of two cutaneous and two muscular branches. The cutaneous branches are the **intermediate** and **medial femoral cutaneous nerves**. The muscular branches are given off to sartorius and pectineus. The former enters the upper part of sartorius, the latter passes medially behind the femoral sheath to enter the anterior surface of the pectineus (which is often supplied also on its deep surface by a branch from the obturator nerve).

The **deep group** consists of four muscular branches to the quadriceps muscle and one cutaneous branch, the saphenous nerve, to the skin of the medial side of the leg and foot.

The **nerve to rectus femoris** is usually double; the upper nerve gives a proprioceptive branch to the hip joint (Hilton's law).

The **nerve to vastus medialis** is the largest of the muscular branches, equalling in size the saphenous nerve itself. It passes down on the lateral side of the femoral artery (Fig. 3.1A) and at a point just below the apex of the femoral triangle, i.e. in the upper part of the adductor canal, it gives branches to the upper part of vastus medialis, while the rest of the nerve continues downwards to supply the lower part of the muscle and the capsule of the knee joint. Of all the muscular branches of the femoral nerve this branch contains most proprioceptive fibres to the knee joint, a fact

which accounts for its large size. The nerve is often double.

The **nerve to vastus lateralis** slopes steeply downwards with the descending branch of the lateral femoral circumflex artery and enters the anterior border of vastus lateralis.

The **nerve to vastus intermedius** passes deeply to enter the upper fleshy part of its anterior surface.

The **saphenous nerve** leaves the femoral triangle at its lower angle and in the subsartorial canal passes across the front of the femoral artery to reach its medial side (Fig. 3.1A). It gives twigs to the subsartorial plexus and leaves the canal by passing beneath the posterior border of sartorius.

Quadriceps femoris

This muscle, the largest in the body, is the main extensor of the knee joint and has four parts: rectus femoris and the three vastus muscles—lateralis, intermedius and medialis. All converge to form the quadriceps tendon which contains the patella (kneecap) and which continues down as the patellar ligament to be inserted into the tuberosity of the tibia.

Rectus femoris arises from the ilium by two heads (Figs 3.13 and 3.17). The *reflected head* arises from a shallow concavity above the acetabulum; it is the primary head, present in quadrupeds. The *straight head* arises from the upper half of the anterior inferior spine, just above the iliofemoral ligament; it is a secondary attachment of the muscle associated with the erect posture of man, and is not present in quadrupeds. The rectus femoris is a spindle-shaped muscle, bipenniform. Above the patella it flattens to form the anterior lamina of the quadriceps tendon. The posterior surface of the muscle is clad in a thick glistening aponeurosis that glides on the anterior surface of vastus intermedius. The anterior surface of the muscle is fleshy except above, where it is covered with a similar aponeurosis—here the muscle bears on a fibrofatty pad beneath the upper end of sartorius. The edges of the muscle belly itself are free but the medial border of the tendon receives an insertion of vastus medialis.

Vastus lateralis has an extensive linear origin from the upper half of the intertrochanteric line (Fig. 3.10), the lateral lip of the linea aspera and the upper two-thirds of the lateral supracondylar line of the femur. It also arises from the lateral intermuscular septum, a strong membrane that lies in the *posterior midline* of the upper thigh (Fig. 3.8). The muscle is largest here and tapers off as it spirals down to be received into the quadriceps tendon (Fig. 3.12). Its deep surface is clad in a glistening sheet of aponeurosis

equally as strong as the fascia lata itself; the sheet glides on the underlying vastus intermedius. The anterior edge of the muscle lies free on vastus intermedius; the descending branch of the lateral circumflex artery and the nerve to vastus lateralis lie in the shallow gutter between the two.

Vastus intermedius arises from the greater trochanter and from the anterior and lateral surfaces of the upper two-thirds of the shaft of the femur — the medial surface of the femoral shaft is bare bone. The anterior surface of the muscle is covered by an aponeurosis which is continued down into the quadriceps tendon.

The small **articularis genu** is a flat ribbon of muscle which arises beneath vastus intermedius (sometimes fused with it) and is inserted into the upper convexity of the suprapatellar bursa (Fig. 3.28).

Vastus medialis arises from the spiral line and the medial lip of the linea aspera and from the tendon of adductor magnus below the hiatus for the femoral vessels. The muscle slopes around the medial surface of the femur. Its anterior border is free above, lying on vastus intermedius; below this it is inserted into the aponeurosis of vastus intermedius, and lower still into the tendon of rectus femoris, while the lowest fibres of all, lying nearly horizontal, are inserted directly into the medial border of the patella. These fibres are indispensable to the stability of the patella (see below).

The **quadriceps tendon** is trilaminar. The aponeurosis of the insertion of vastus lateralis lies sandwiched between that of vastus intermedius and rectus femoris; the three laminae are fused together by mutual interchange of fibres. A thin sheet passes across the front of the patella into the patellar ligament and the retinacula.

The **patellar ligament** connects the lower border of the patella with the smooth convexity on the tuberosity of the tibia (Fig. 3.60). The **patellar retinacula** are fibrous expansions from the quadriceps which connect the sides of the patella with the lower margins of the condyles of the tibia. They are attached also to the sides of the ligament.

Nerve supplies. Each muscle is supplied by its own branch from the femoral nerve (L3, 4; p. 156).

Actions. The muscle is the main extensor of the knee joint (p. 183) making with the buttock and calf muscles the great propulsive mass for walking, running, jumping, etc. The attachment of rectus femoris to the pelvic girdle has a stabilizing effect on the hip joint and can assist iliopsoas to flex the hip. In propulsive movements hip extension elongates the rectus femoris, which thus contracts more powerfully in the simultaneous extension of the knee.

Test. While lying on the back with the knee partly

flexed, the patient extends the knee against resistance. Rectus femoris should be seen and felt.

Stability of the patella

The patella is a sesamoid bone. It is mobile from side to side. The patellar ligament is vertical, but the pull of the quadriceps is oblique, in the line of the shaft of the femur; when the muscle contracts it tends to draw the patella laterally. Three factors discourage this lateral dislocation; they are the usual bony, ligamentous and muscular factors that control the stability of any bone. The bony factor consists in the forward prominence of the lateral condyle of the femur (Fig. 3.11), the ligamentous factor is the tension of the medial patellar retinaculum, but they are in themselves incapable of preventing lateral displacement of the patella. The lowest fibres of vastus medialis, inserted into the border of the bone, hold the patella medially when the quadriceps contracts (Fig. 3.12). These fibres of vastus medialis are indispensable to the stability of the patella. They waste very rapidly after effusion into the knee joint; the patella is then carried laterally by contraction of the quadriceps, and proprioceptive impulses from the joint are interpreted as an unstable knee. However, it is not just for patellar stability that the lowest fibres of vastus medialis are important; they are vital for *complete extension* of the knee joint (p. 183). When these fibres are paralysed, or wasted as after prolonged bed rest, the knee feels unsteady and the last 20° or so of extension are not possible.

Adductor canal

This canal (also known as the subsartorial or Hunter's canal) is a gutter-shaped groove between vastus medialis and the front of the adductor muscles, below the apex of the femoral triangle. The gutter is roofed in by a fascia which contains in its meshes the subsartorial plexus. The canal so formed contains the femoral artery and vein, the saphenous nerve and, in the upper part, the nerve to vastus medialis (Fig. 3.1). Sartorius lies on the fascial roof. The adductors in the floor of the canal are the adductor longus above and the adductor magnus below. The **subsartorial plexus** receives small branches from the intermediate cutaneous nerve of the thigh, the saphenous nerve and the anterior division of the obturator nerve. The plexus supplies the overlying fascia lata and an area of skin above the medial side of the knee. The femoral vessels leave the canal by passing into the popliteal fossa through the hiatus between the hamstring and adductor parts of the adductor magnus muscle. The vein spirals gradually

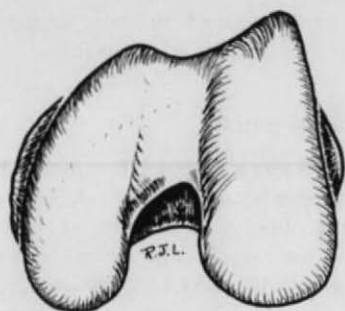


Fig. 3.11 Lower end of the left femur, from below. The prominence of the lateral condyle discourages lateral displacement of the patella.

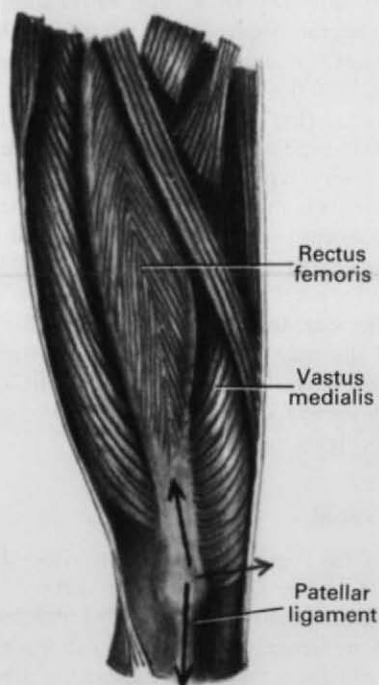


Fig. 3.12 Stabilization of the patella. The slightly oblique pull of rectus femoris is counteracted by the lowest fibres of vastus medialis.

around the artery. At the adductor magnus hiatus the vein is lateral (i.e. next to the femur) but ascends posteriorly until in the femoral triangle it lies medial to the artery. This is in keeping with the rotation medially of the lower limb from the fetal position, and is further reflected in the spiral manner in which the saphenous nerve passes across the femoral artery. *At all levels in the thigh the artery lies between saphenous nerve and femoral vein.* Below the opening in the adductor magnus the

canal is occupied by the saphenous nerve and the *descending genicular artery* (anastomotica magna). This branch leaves the femoral artery just above the hiatus and, passing downwards, divides into a superficial saphenous artery that accompanies the saphenous nerve and a deep muscular branch that enters the vastus medialis and joins the arterial anastomosis around the knee.

The **saphenous nerve** passes out of the canal by escaping from beneath the posterior border of the sartorius (in front of the gracilis) whence it passes downwards with the great saphenous vein. Just before leaving the canal the *infrapatellar branch* is given off; this nerve pierces sartorius and joins the patellar plexus.

PART 2

MEDIAL COMPARTMENT OF THE THIGH

The contents of this (adductor) compartment of the thigh are separated from the anterior (extensor) compartment by the medial intermuscular septum, but there is no septum dividing them from the posterior (flexor or hamstring) compartment. The muscles consist of gracilis and the three adductors, longus, brevis, and magnus, while deeply lies obturator externus. The nerve of the compartment is the obturator, and the artery is the profunda femoris, assisted proximally by the obturator artery.

The **medial intermuscular septum** lies deep to the femoral vessels and is a downward continuation of the fascia on the pectineus, i.e. of the fascia lata in the floor of the saphenous opening. It is quite thin. It is attached to the linea aspera, and passes over the anterior surfaces of pectineus, adductor longus and the lower part of adductor magnus in the floor of the adductor canal. Its medial edge is attached to the fascia lata. It is a thin layer, amounting to little more than the areolar tissue found on the surface of any muscle; this is in marked contrast with the dense lateral septum (Fig. 3.8).

Gracilis

This, the most superficial muscle of the medial side of the thigh, arises as a flat sheet from the edge of the inferior ramus of the pubis (Fig. 3.13), just beneath the fascia lata. Its origin extends inferiorly to encroach a little on the ischial ramus, but it is supplied by the obturator, the nerve of the pubis. The sheet of muscle

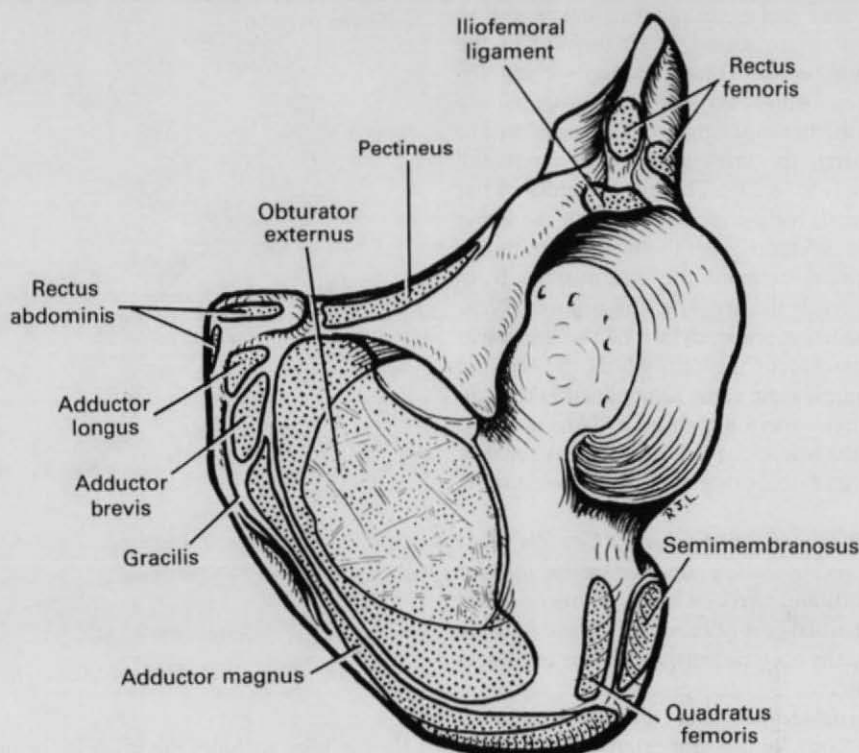


Fig. 3.13 Muscle attachments to the lower part of the lateral surface of the left hip bone.

narrows in triangular fashion and in the lower third of the thigh is replaced by a cylindrical tendon which is inserted into the subcutaneous surface of the shaft of the tibia just behind sartorius, from whose tendon it is separated by a bursa.

Adductor longus

This, the most superficial of the three adductors, arises from a circular area on the body of the pubis, in the angle between the pubic crest and symphysis (Fig. 3.13), by a strong round tendon, sometimes ossified ('rider's bone'). The muscle rapidly becomes fleshy and flattens out to be inserted by an aponeurotic flat tendon into the lower two-thirds of the linea aspera of the shaft of the femur.

Adductor brevis

This muscle arises from the body and inferior ramus of the pubic bone, deep to pectineus and adductor longus (Fig. 3.13). It widens in triangular fashion to be inserted into the upper part of the linea aspera immedi-

ately lateral to the insertion of pectineus and above that of adductor longus. The anterior division of the obturator nerve passes vertically downwards on its anterior surface (Fig. 3.1); the posterior division passes down behind it. The oblique upper border of adductor brevis thus lies between the two divisions of the obturator nerve in the same way as the upper border of adductor longus lies between the femoral and the profunda femoris vessels.

Adductor magnus

This is a composite muscle formed by the fusion of adductor and hamstring muscle masses (hence the absence of a septum between the adductor and hamstring compartments of the thigh), each with their own nerve supply.

The *hamstring part* arises from the lateral surface of the lower part of the ischial tuberosity (Fig. 3.54), and the fibres pass vertically downwards to a tendinous attachment to the adductor tubercle of the femur, with an expansion to the medial supracondylar line. In continuity with the ischial origin, the true *adductor part* arises

from the ischiopubic ramus (Fig. 3.13), below and in front of obturator externus and as far forward as the origin of adductor brevis. Traced forwards along the bony origin, these fibres are inserted progressively higher along the medial supracondylar line (adjacent to the hamstring part), the linea aspera and up to the gluteal tuberosity (Fig. 3.23). The upper border of the muscle is horizontal, lying edge to edge with the lower border of quadratus femoris, and the medial circumflex femoral artery passes between the two muscles from front to back to reach the cruciate anastomosis. Near the top of the medial supracondylar line there is a gap in the muscle attachment through which the femoral vessels pass, changing their name to popliteal as they do so. Along the linea aspera attachment there are four small openings, the lowest for the end of the profunda femoris vessels, and the others for their perforating branches.

Nerve supplies of adductors. Gracilis and adductor longus and brevis are supplied by the anterior division of the obturator nerve, with the hamstring part of magnus by the tibial part of the sciatic nerve and the rest of magnus by the posterior division of the obturator (L2, 3 for all muscles).

Actions of adductors. The adductor mass of muscles, though large, is less important in the prime movement of adduction than in postural and synergic activities during other movements, particularly those of the hip (discussed on p. 168). Older anatomists gave the pair of gracilis muscles the whimsical name of 'custodes virginittatis'.

Tests for adductors. While lying on the back with the knee straight, the patient adducts the thigh against resistance, and the upper ends of gracilis and adductor longus are palpated.

Obturator externus

This muscle arises from the whole of the obturator foramen. Both membrane and muscle fall short of the obturator notch above, thereby forming a short canal for the passage of the obturator nerve and vessels (Fig. 3.13). The muscle passes laterally and posteriorly beneath the neck of the femur where it narrows into a tendon that spirals in contact with the back of the femoral neck to be inserted on the medial surface of the greater trochanter into the deep pit, the trochanteric fossa. The capsule of the hip joint extends along the neck of the femur only as far as the place where obturator externus tendon is in contact with periosteum, namely half the neck of the femur (Figs 3.14 and 3.15), whereas in front the capsule of

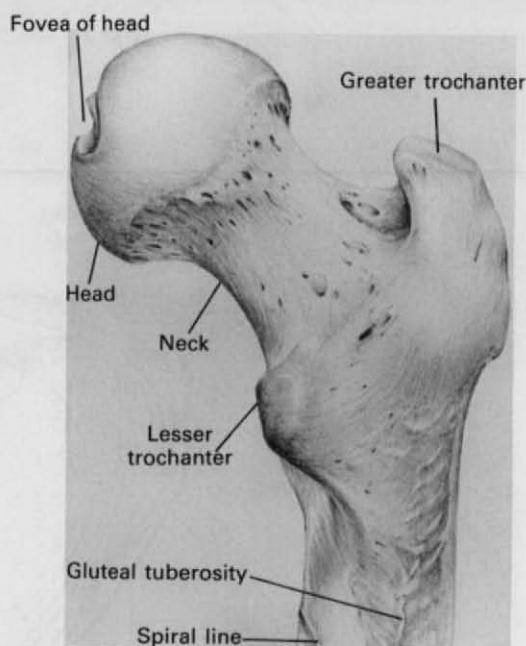


Fig. 3.14 Upper end of the right femur, from behind.

the hip joint includes the whole of the neck of the femur (Figs 3.9 and 3.10).

Nerve supply. By the posterior division of the obturator nerve (L3, 4).

Action. With the other short muscles around the hip joint, it stabilizes and supports the proximal part of the limb. Its line of pull passes behind the hip joint; acting as a prime mover it is a lateral rotator of the femur.

Obturator artery and nerve

The **obturator artery**, on emerging from the obturator foramen with the nerve, divides into medial and lateral branches that encircle the origin of obturator externus and anastomose with each other and with the medial circumflex artery. From the lateral branch the *articular* twig to the hip joint arises; it enters the acetabular notch and runs in the ligament of the head of the femur to supply a small scale of bone in the region of the pit for the attachment of the ligament (p. 168).

The **obturator nerve** divides in the obturator notch into anterior and posterior divisions; the anterior passes above obturator externus, the posterior passes through the upper border of the muscle, giving off a branch to supply it before doing so.

The *anterior division*, giving an articular branch to the

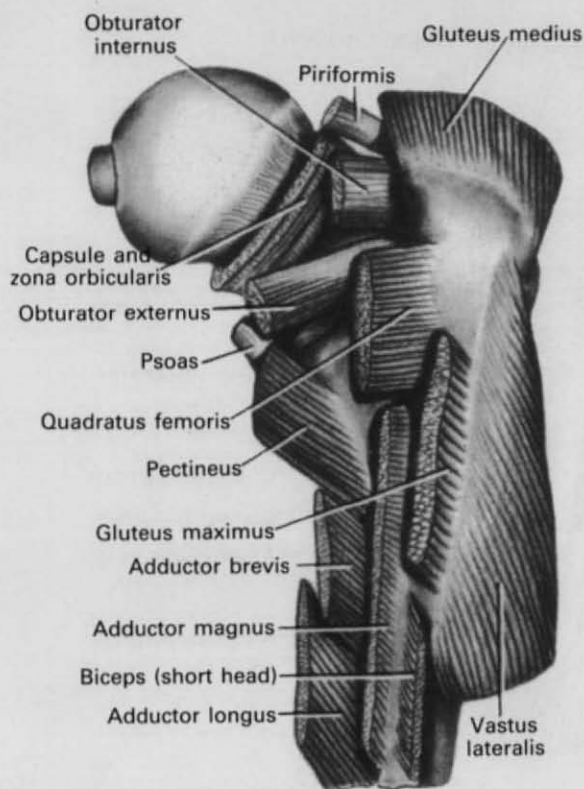


Fig. 3.15 Attachment at the upper end of the right femur, from behind.

hip joint, descends in the thigh behind the adductor longus, which it supplies. Passing over the anterior surface of adductor brevis (Fig. 3.1) it supplies that muscle and gracilis and ends in the subsartorial plexus, whence branches supply the skin over the medial side of the thigh. Direct branches to the skin are often given off at a level above the subsartorial plexus (Fig. 3.52).

The *posterior division* emerges through obturator externus (having already supplied that muscle), and passes vertically downwards on adductor magnus deep to the other adductor muscles. It supplies adductor magnus and gives off a fine terminal branch which runs with the femoral artery through the hiatus in the muscle to the popliteal fossa and supplies the capsule of the knee joint by passing in with the middle genicular artery (Hilton's law, p. 12). Note that the anterior and posterior divisions straddle the adductor brevis muscle in a manner similar to that in which the femoral and profunda femoris vessels straddle adductor longus.

PART 3 GLUTEAL REGION AND HIP JOINT

The gluteal region or buttock lies behind the pelvis, and extends from the iliac crest to the gluteal fold (fold of the buttock) which is the posterior horizontal crease line of the hip joint. Various muscles, nerves and vessels emerge from the pelvis to enter the lower limb in this region. The muscles of the region are the three gluteal—gluteus maximus, medius and minimus—and the deeply placed piriformis, obturator internus, superior and inferior gemellus, and quadratus femoris (Fig. 3.16). Bony and ligamentous features of the region include the back of the sacrum and hip bone, the upper end of the femur, and the sacrotuberous and sacrospinous ligaments. The greater sciatic foramen is formed above and in front by the greater sciatic notch of the hip bone, behind by the sacrotuberous ligament, and below by the sacrospinous ligament. The lesser sciatic foramen is formed by the lesser sciatic notch of the hip bone, and the same two ligaments. The ligaments cross each other and so convert the two sciatic notches into foramina.

Subcutaneous tissue

The panniculus adiposus is well developed in the gluteal region and gives to the buttock its characteristic convexity. The fold of the buttock is the transverse skin crease for the hip joint and is *not* caused by the lower border of the gluteus maximus, which crosses the line of the fold *obliquely*. The *blood supply* of the skin and fat is derived from perforating branches of the superior and inferior gluteal arteries, and the lymphatic drainage is into the lateral group of the superficial inguinal lymph nodes.

The **cutaneous nerves** of the buttock (Fig. 3.53) are derived from posterior and anterior rami. The posterior rami of the upper three lumbar nerves slope downwards over the iliac crest to supply the upper skin of the buttock. The posterior rami of all five sacral nerves are cutaneous. The upper three supply the skin of the natal cleft, the lower two, with the coccygeal nerve, supply skin over the coccyx.

The anterior rami are derived from widely separated segments. The upper part of the lateral skin is supplied by lateral cutaneous branches of the subcostal and iliohypogastric nerves (T12 and L1), the lower part by branches of the lateral femoral cutaneous nerve (L2). The perforating cutaneous nerve and branches of the posterior femoral cutaneous nerve supply the lower

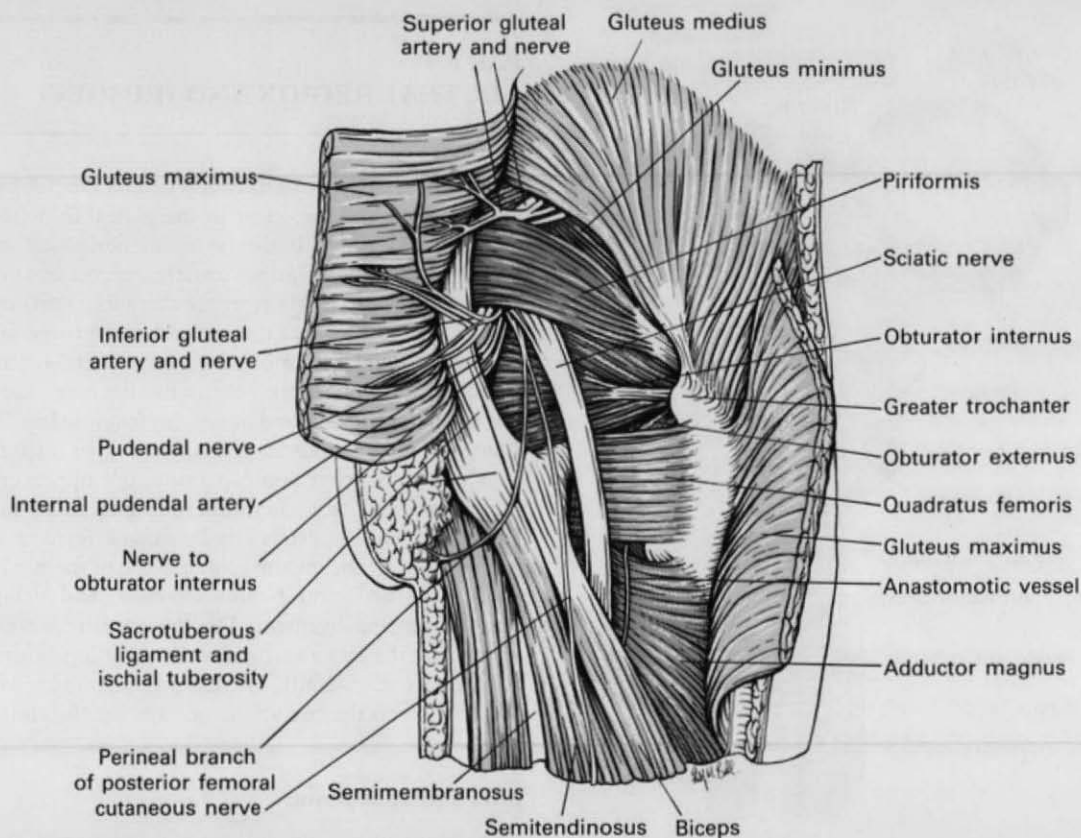


Fig. 3.16 Right gluteal region, with much of gluteus maximus removed.

central part of the buttock. The former is derived from two branches of the sacral plexus (S2 and 3) and the nerve passes backwards to pierce the sacrotuberous ligament and the lower part of gluteus maximus to reach the deep fascia and skin. Thus the segments between L2 and S2 are not represented in the skin of the buttock; their dermatomes lie peripherally, in the skin of the limb (Fig. 1.17, p. 24). The fault so produced is responsible for the posterior axial line. See page 24 for remarks on dermatomal patterns.

Gluteus maximus

This is the largest and the most superficial of the gluteal muscles, and it is characterized by the large size of its fibres. A thick flat sheet of muscle, it slopes from the pelvis down across the buttock at 45° (Fig. 3.16). Its oblique lower border takes no part in forming the gluteal fold, which is the horizontal skin crease of the hip joint with bulging fat above it. It arises from the gluteal surface of the ilium behind the posterior

gluteal line, from the lumbar fascia, from the lateral mass of the sacrum below the auricular surface, and from the sacrotuberous ligament. The deep half of its lower half lies behind the greater trochanter and is inserted into the gluteal tuberosity of the femur (Fig. 3.15). The remaining three-quarters of the muscle, enclosed by a splitting of the fascia lata, is inserted into the upper end of the iliotibial tract in common with the tensor fasciae latae.

There are usually three *bursae* beneath the muscle: one over the ischial tuberosity and the hamstring origins, one over the lateral side of the greater trochanter, and another over the upper part of vastus lateralis.

The blood supply comes from both the superior and inferior gluteal arteries, and the veins form a plexus beneath the muscle.

Nerve supply. By the inferior gluteal nerve (L5, S1, 2), the only muscle supplied by this nerve. It enters the deep surface on the medial side, nearer its origin than its insertion.

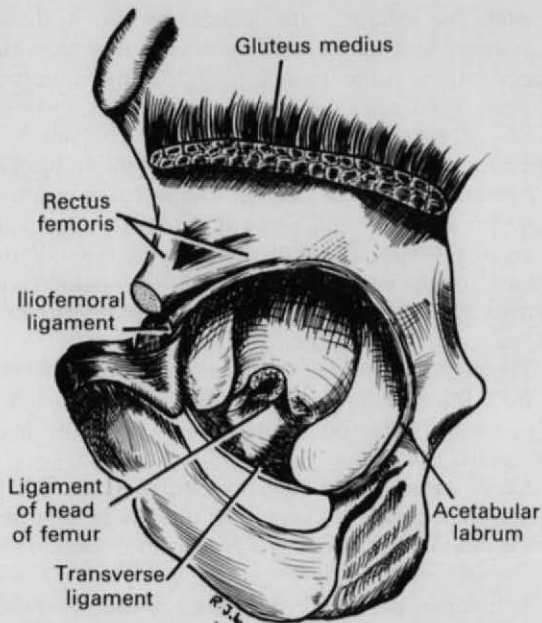


Fig. 3.17 Left acetabulum and adjacent structures.

Action. Its action on the femur is a combination of lateral rotation and extension at the hip joint, while through the iliotibial tract its contraction supports the extended knee. In paralysis of quadriceps femoris it can become an active but weak extensor. It can be felt in contraction in standing with hip and knee each slightly flexed, in which case it is a powerful antigravity muscle. In this position the muscle can be felt in ever-increasing contraction as the body bends forwards more and more at the hip. It comes into play as an extensor of the hip joint chiefly at the extremes of hip movement, as in running, climbing stairs, etc., and it is called into play little if at all in the mid-position of the hip joint, as in quiet walking, when the main extensors of the hip are the hamstrings. It is the chief antigravity muscle of the hip during the act of sitting down from standing, controlling flexion of the hip joint.

Test. While lying face down with the leg straight, the patient tightens the buttock and extends the hip. The examiner observes and palpates the muscle.

Gluteus medius

This muscle can be seen in its entirety only when the gluteus maximus is removed. It arises from the gluteal surface of the ilium between the middle and posterior gluteal lines (Fig. 3.54). Note that the middle gluteal line meets the iliac crest halfway between the tubercle

and the anterior superior spine; thus with the hip bone held in the correct anatomical position it can be seen that the free anterior borders of gluteus medius and gluteus minimus lie edge to edge. The gluteus medius converges in triangular fashion towards the *upper margin* and *lateral surface* of the greater trochanter, into which it is inserted (below an underlying bursa) along an oblique line that slopes downwards and forwards from the apex of the trochanter (Fig. 3.15). Its tendon of insertion gives a strong expansion that crosses the capsule of the hip joint to blend with the upper end of the iliofemoral ligament (Fig. 3.18). A bursa separates the upper part of the lateral surface of the greater trochanter from the tendon.

Gluteus minimus

The muscle arises under cover of gluteus medius (Fig. 3.16) from the gluteal surface of the ilium between the middle and inferior lines, whence its fibres converge (below an underlying bursa) to a J-shaped area on the *anterior surface* of the greater trochanter (Fig. 3.10). Its anterior border lies edge to edge with that of gluteus medius from origin to insertion.

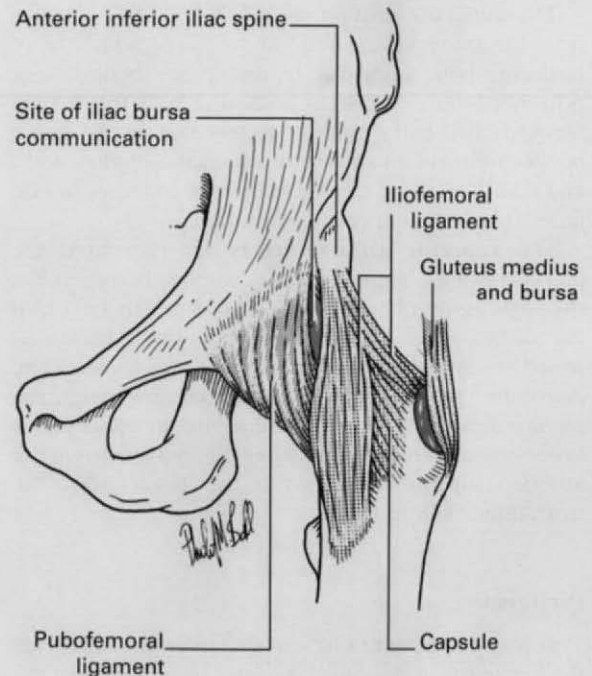


Fig. 3.18 Ligaments of the left hip joint, from the front. The iliac bursa may communicate with the joint between the pubofemoral and iliofemoral ligaments.

Nerve supplies. Gluteus medius and minimus are supplied by the superior gluteal nerve (L4, 5, S1).

Actions. These two muscles abduct the hip joint. This is not a very common event; the two muscles are constantly called into play, however, to *prevent adduction* at the hip when the weight of the body is supported on one leg. In this they are assisted by tensor fasciae latae (p. 150). Thus in walking the muscles of the two sides are alternately contracting; they also provide the pelvic rotation that accompanies walking (p. 169). They can be palpated above the upper border of gluteus maximus—feel them in walking and note their contraction when their own leg bears weight. If they are paralysed the gait is markedly affected, the trunk swaying from side to side towards the weight-bearing limb to prevent downward tilting of the pelvis on the unsupported side.

Test. While lying face down with the leg flexed to a right angle, the patient turns the foot outwards against resistance. Gluteus medius is palpated below the iliac crest behind tensor fasciae latae which can also be felt contracting. In the *Trendelenburg test* with the patient standing on one leg, the pelvis on the opposite side should rise slightly; if it falls due to loss of abductor power the test is positive.

The **superior gluteal nerve** (L4, 5, S1) emerges from the greater sciatic notch above the upper border of piriformis and immediately disappears beneath the posterior border of gluteus medius (Fig. 3.16). It runs forwards below the middle gluteal line in the space between gluteus medius and minimus, supplies both, and ends by sinking into the substance of tensor fasciae latae. It has no cutaneous distribution.

The **superior gluteal artery** emerges from the pelvis above the upper border of piriformis and, unlike the nerve, gives off a *superficial branch* which sinks into the deep surface of the overlying gluteus maximus, which it penetrates to supply the overlying skin. The *deep branch* passes laterally in the space between gluteus medius and minimus and divides into an upper and a lower branch. The upper reaches the anastomosis at the anterior superior iliac spine, the lower joins the trochanteric anastomosis.

Piriformis

This is an important muscle in that its relations provide the key to the understanding of the arrangement of the structures in the gluteal region (Fig. 3.16). The muscle arises from the middle three pieces of the sacrum and passes laterally behind the sacral plexus to emerge

through the greater sciatic foramen, which it almost completely fills. Some additional fibres arise from the upper margin of the notch (Fig. 3.54). In the buttock its upper border lies alongside gluteus medius, its lower border alongside the superior gemellus. It converges into a rounded tendon which is inserted into the apex of the greater trochanter (that is, the posterior intumed end of its upper border). Some of its fibres run forwards along the whole length of the upper border of the greater trochanter, outlining with the tendons of gluteus medius and minimus a triangle of insertion on the greater trochanter (Fig. 3.16).

The *surface marking* of the lower border of piriformis is from the midpoint of a line between the posterior superior iliac spine and the tip of the coccyx to the tip of the greater trochanter.

Nerve supply. By the anterior rami of S1 and S2.

Action. To aid the other short muscles in adjusting and stabilizing the hip joint, especially in abduction.

A number of structures emerge from the pelvis through the greater sciatic foramen into the gluteal region; to do so they pass above or below the piriformis muscle. *Above* the upper border emerge the superior gluteal nerve and vessels. *Below* the lower border emerge the inferior gluteal nerve and vessels, the pudendal nerve and vessels, the nerve to obturator internus, and the sciatic nerve with the posterior femoral cutaneous nerve on its surface and the nerve to quadratus femoris deep to it.

The **inferior gluteal nerve** (L5, S1, 2) leaves the pelvis beneath the lower border of piriformis and sinks into the deep surface of gluteus maximus (Fig. 3.16). Its course in the buttock is short. It enters the muscle towards its origin (medial end of muscle). It has no cutaneous distribution.

The **inferior gluteal artery** appears in the buttock between piriformis and the superior gemellus. It breaks up into muscular branches which supply piriformis, obturator internus, and gluteus maximus. It sends anastomotic branches to the trochanteric and cruciate anastomoses. One branch, the *companion artery to the sciatic nerve*, is of interest as being the remnant of the original axial artery of the limb in the embryo, resembling in this respect the artery to the median nerve from the anterior interosseus artery. The artery supplies the sciatic nerve and rarely may persist as a very large vessel.

The **pudendal nerve** (S2, 3, 4) makes but a brief appearance in the buttock (Fig. 3.16). On emerging from beneath piriformis the nerve turns forward around the sacrospinous ligament, on which it lies just medial to the spine of the ischium. It leaves the buttock by

passing forward through the space between the sacrotuberous and sacrospinous ligaments (the lesser sciatic foramen) (Fig. 5.67, p. 405).

The **internal pudendal artery** follows a similar course to that of the nerve, and lies on its lateral side. It crosses the tip of the ischial spine, against which it can be compressed to control arterial haemorrhage in the perineum. A companion vein lies on each side of the artery.

The **nerve to obturator internus** (L5, S1, 2) lies still more laterally and loops around the base of the ischial spine (Fig. 3.16) and then passes forward to sink into the muscle, deep to its fascia, in the side wall of the ischioanal fossa (Fig. 5.66, p. 404). It supplies also the superior gemellus.

The **sciatic nerve** (L4, 5, S1, 2, 3) emerges from below the piriformis muscle more laterally than the inferior gluteal and pudendal nerves and vessels (Fig. 3.16). It lies upon the ischium over the posterior part of the acetabulum. It is in contact with bone at a point one-third of the way up from the ischial tuberosity to the posterior superior iliac spine; this point is the surface marking for the entry of the nerve into the gluteal region. It is the nerve of the ischium or 'ischiodic' nerve. It passes vertically down over obturator internus and quadratus femoris to the hamstring compartment of the thigh, where it disappears under cover of the biceps femoris. In the buttock it lies under cover of gluteus maximus midway between the greater trochanter and the ischial tuberosity, which is the surface marking of the nerve at the top of the thigh (Fig. 3.23).

Its tibial and common peroneal (fibular) components usually separate in the upper part of the popliteal fossa but occasionally there is a high division and the two components may leave the pelvis separately, in which case the common peroneal nerve (L4, 5, S1, 2) will be found piercing the lower part of piriformis while the tibial nerve (L4, 5, S1, 2, 3) emerges from beneath the muscle in the ordinary way.

The **posterior femoral cutaneous nerve** (S2, 3) emerges from beneath piriformis and in its course in the buttock it lies on the sciatic nerve under cover of gluteus maximus. Below the buttock the nerve passes vertically down the midline of the back of the thigh and leg as low as the lower parts of the gastrocnemius muscle bellies, midway between knee and ankle. It lies *beneath the fascia lata*, superficial to the hamstrings, which separate it from the sciatic nerve, and supplies the fascia and overlying skin by a series of perforating branches. Its other branches are: gluteal, a branch (or two) curling around the lower border of gluteus maximus to supply fascia and skin over the prominent

convexity of the buttock (Fig. 3.53); and *perineal*, a long branch which winds medially and forward between gracilis and the fascia lata at the root of the limb to supply the posterior part of the scrotum or labium majus.

It is significant that the segments (S2, 3) of this nerve are also those of the pelvic parasympathetic nerves which supply the derivatives of the cloaca. Pain from pelvic disease is often referred over the distribution of the posterior femoral cutaneous nerve, and such pain along the back of the thigh and calf must be distinguished from sciatica.

The **nerve to quadratus femoris** (L4, 5, S1) lies on the ischium beneath the sciatic nerve (Fig. 3.16). It passes over the back of the hip joint, to which it gives an *articular branch* (Hilton's law). In this situation it lies deep to obturator internus and the gemelli, which thus separate it from the overlying sciatic nerve. It runs downwards to sink into the deep (anterior) surface of quadratus femoris. It supplies also the inferior gemellus.

Obturator internus and gemelli

Obturator internus plugs the lateral part of the lesser sciatic foramen and after arising from the lateral wall of the pelvis (p. 374) makes a right-angled bend around the lesser sciatic notch of the ischium (Fig. 3.16). Its deep surface is strongly tendinous and its pressure leaves grooves on the fresh bone, which is here covered with fibrocartilage. The bursa beneath the muscle on the side wall of the pelvis extends backwards to lubricate the muscle as it plays over the lesser sciatic notch. As the muscle emerges into the buttock it is reinforced by additional muscle fibres arising from the margins of the lesser sciatic notch. These are the superior and inferior gemelli and they form, with the obturator internus, a *tricipital tendon* which is inserted into the *medial surface* of the greater trochanter where the bone rises above the neck of the femur and the trochanteric fossa (Fig. 3.15). The somewhat faceted *smooth* area of this insertion can be seen on inspection of the femur.

Nerve supply. By its own nerve (see above).

The **superior gemellus** arises from the spine of the ischium and is supplied by the nerve to obturator internus, while the **inferior gemellus** arises from the ischial tuberosity at the margin of the lesser sciatic notch and is supplied by the nerve to quadratus femoris (Fig. 3.54).

The tricipital tendon of obturator internus and the gemelli lies horizontal in the buttock, its upper border alongside piriformis, its lower border edge to edge with quadratus femoris. The sciatic nerve passes down on its

surface, the nerve to quadratus femoris deep to it. Obturator internus, as it emerges from the lateral wall of the pelvis, plugs the lateral part of the lesser sciatic foramen, and the strong fascia over the muscle (parietal pelvic fascia) is attached to both ligaments and does not project into the buttock. The medial part of the foramen forms a funnel-shaped orifice which leads forwards into the pudendal canal; the internal pudendal vessels and pudendal nerve entering the foramen from the buttock are thus directed into the canal (Fig. 5.67, p. 405).

Quadratus femoris

This muscle, true to its name, is rectangular (Fig. 3.16). It arises from the ischial tuberosity immediately below the inferior gemellus, and passes laterally. It is inserted into the quadrate tubercle of the femur and into a line (not visible on most bones) that passes vertically downwards therefrom to a level that bisects the lesser trochanter (Fig. 3.15). It should be noted that the 'quadrate tubercle' is a heaping up of bone at the site of fusion of the epiphysis of the greater trochanter (like the ilipubic eminence of the hip bone) and is not itself produced by the pull of the quadratus femoris. The upper and lower borders of the muscle are horizontal and parallel and they lie edge to edge with the inferior gemellus above and the free upper border of adductor magnus below.

Nerve supply. By its own nerve (L4, 5, S1; p. 165).

Actions. The actions of obturator internus and quadratus femoris like that of piriformis are primarily synergic, to act with other short muscles of the hip to adjust and stabilize the joint. Acting as prime movers they are lateral rotators of the femur, but in the sitting position they can act as abductors (p. 169).

Trochanteric anastomosis

This provides the main source of blood for the supply of the head of the femur. The anastomosis lies near the trochanteric fossa. It is formed by anastomosis of the descending branch of the superior gluteal artery with the ascending branches of both lateral and medial circumflex femoral arteries. The inferior gluteal artery usually joins the anastomosis. Branches from the anastomosis pass along the femoral neck beneath the retinacular fibres of the capsule (p. 167).

Cruciate anastomosis

At the level of the middle of the lesser trochanter the transverse branch of the medial circumflex femoral

artery meets the transverse branch of the lateral circumflex femoral at the lower border of the insertion of quadratus femoris. They are joined by an ascending branch of the first perforating artery and the cross is completed above by a descending branch of the inferior gluteal artery.

Gluteal intramuscular injection

The upper outer quadrant of the gluteal region is a common site for intramuscular injections, but in order to avoid damage to the sciatic nerve it is absolutely essential to recall the proper definition of this region called the buttock; it extends from the iliac crest to the gluteal fold (fold of the buttock). Only when the quadrants are estimated using the *iliac crest* as the upper boundary of the region can the proper injection site, the *upper outer quadrant*, be chosen correctly to avoid the sciatic nerve. The needle may pass through the gluteal fascia into gluteus medius or straight into gluteus maximus depending on the exact position chosen.

HIP JOINT

In general it can be said that in all joints stability and range of movement are in inverse proportion to each other; the **hip joint** provides a remarkable example of a high degree of both. It is a synovial joint of the ball and socket variety. Its stability is largely the result of the adaptation of the articulating surfaces of acetabulum and femoral head to each other, and its great range of mobility *results from the femur having a neck that is much narrower than the equatorial diameter of the head.*

The **acetabulum** is formed by fusion of the three components of the hip bone. Ilium, ischium, and pubis meet at a Y-shaped cartilage which forms their epiphyseal junction. This epiphysis closes after puberty (compare with the glenoid cavity of the scapula). The site of union can be seen on the hip bone by a heaping up of bone at the ilipubic eminence and at the meeting place of ilium and ischium, about a third of the way down the greater sciatic notch. These sites indicate the position of the upper limbs of the Y-shaped epiphyseal cartilage; the stem of the Y is vertical and passes through the acetabular notch to the obturator foramen. The acetabular articular surface, covered with hyaline cartilage, is a C-shaped concavity. Its peripheral edge is deepened by a rim of fibrocartilage—the **acetabular labrum**—which encloses the femoral head beyond its equator, thus increasing the stability of the joint. The labrum is continued across the acetabular notch as the **transverse ligament**, which, unlike the labrum, has

no cartilage cells. The transverse ligament gives attachment to the ligament of the head of the femur (Fig. 3.17). The central non-articular part of the acetabulum is occupied by a pad of fat (the Haversian pad).

The spherical head of the femur is adapted to the concavity of the articular surface of the acetabulum. The neck of the femur is narrower than the equatorial diameter of the head and considerable movement in all directions is possible before the femoral neck impinges upon the acetabular labrum. The presence of a relatively narrow neck is the mechanical factor responsible for the wide range of movement in such a stable joint. (The shoulder joint, mechanically, is in marked contrast with the hip joint in this respect.) The head of the femur is covered with hyaline cartilage which, in many cases, encroaches a little on the anterior surface of the neck for articulation with the acetabulum when the hip is flexed (Fig. 3.9). The non-articulating convexity of the head is excavated into a pit (the *fovea*) for attachment of the **ligament of the head of the femur** (ligamentum teres), whose other end is attached to the transverse ligament.

The **capsule** of the joint is attached circumferentially around the labrum and transverse ligament, whence it passes laterally, like a sleeve, to be attached to the neck of the femur. In front it is attached to the intertrochanteric line, but behind it extends for only half this distance, being attached halfway along the femoral neck (Fig. 3.15). The capsule is loose but extremely strong.

From these attachments the fibres of the capsule are reflected back along the neck of the femur, intimately blended with the periosteum, to the articular margin of the femoral head. This reflected part constitutes the **retinacular fibres**, which bind down the nutrient arteries that pass, chiefly from the trochanteric anastomosis, along the neck of the femur to supply the major part of the head. Fracture of the femoral neck within the capsular attachment necessarily ruptures the retinacular fibres and the vessels, causing avascular necrosis of the head.

The fibrous capsule is strengthened by three **ligaments** which spiral around the long axis of the femoral neck. The ligaments arise one from each constituent bone of the hip bone. If the femur is flexed and laterally rotated in such a manner as to restore the fetal position the ligaments are 'unwound' and lie parallel with the femoral neck, and are thus relaxed. The opposite movement (extension and medial rotation) draws them tight.

The **iliofemoral ligament** (of Bigelow) is the strongest of the three, and has the shape of an inverted V

(not the Y of popular belief; Bigelow never so described it!). The base of the 'V' arises from the lower half of the anterior inferior iliac spine and from the acetabular rim. The diverging limbs are attached to the upper and lower ends of the intertrochanteric line, each to a low tubercle visible on most bones. It is difficult to display the ligament as a separate entity, since it is fused with the capsule. The ligament limits extension at the hip joint and is of clinical interest in that it forms the fulcrum or axis around which the neck of the femur rotates in dislocation of the hip joint, as originally noted by Bigelow.

The **pubofemoral ligament** passes from the ilio-pubic eminence and obturator crest to the capsule on the inferior part of the neck of the femur (Fig. 3.18). Abduction combined with extension of the hip pulls it tight.

The **ischiofemoral ligament** is the weakest of the three. It arises from the posteroinferior margin of the acetabulum, and its fibres, passing laterally to the capsule, spiral upwards and are continued into a band of fibres that run in the capsule transversely around the neck of the femur. They form the *zona orbicularis* (Fig. 3.15). Very few fibres reach the femur, and the name *ischiocapsular ligament* is more accurate. The zona serves to keep the loose capsule in good contact with the underlying retinacular fibres (there is no rotator cuff as in the shoulder joint). The zona is responsible for the hourglass constriction of a normal arthrogram.

As in all synovial joints, the **synovial membrane** is attached to the articular margins. From its attachment around the labrum and transverse ligament it lines all the capsule and is reflected back along the neck of the femur, where it invests the retinacular fibres up to the articular margin of the head of the femur. The Haversian fat pad and the ligament of the head are likewise invested in a sleeve of synovial membrane that is attached to the articular margins of the concavity of the acetabulum and of the fovea on the femoral head.

Occasionally (10%) a perforation in the anterior part of the capsule, between the iliofemoral and pubofemoral ligaments, permits communication between the synovial cavity and the iliac bursa (Fig. 3.18). Apart from the iliac bursa, several other bursae are associated with the hip joint. There is one under gluteus medius and one under gluteus minimus at their insertions to the greater trochanter, and three under gluteus maximus (over the ischial tuberosity, greater trochanter and the upper part of vastus lateralis, p. 162).

Anteriorly the iliac bursa lies over the capsule and extends upwards into the iliac fossa beneath iliacus.

The psoas major tendon separates the capsule from the femoral artery and the iliacus muscle separates it from the femoral nerve, while more medially pectineus intervenes between the capsule and the femoral vein. Superiorly there is a loose connective tissue space between the capsule and the overhanging gluteus minimus, and inferiorly obturator externus spirals backwards around the femoral neck. Posteriorly lies piriformis, and below it the tricipital obturator internus and gemelli separate the sciatic nerve from the capsule. Medially the acetabular fossa is thin and translucent; this forms part of the lateral wall of the pelvis and in the female the ovary lies adjacent, separated only by obturator internus, the obturator nerve and vessels and the peritoneum.

Blood supply

The capsule and synovial membrane are supplied from nearby vessels. The head and intracapsular part of the neck receive their blood from the trochanteric anastomosis (p. 166), mainly through branches of the medial circumflex femoral artery. Although the artery in the ligament of the head of the femur (from the obturator artery) is important in the young child, it is usually considered to have atrophied by the age of about 7 years (but bleeding from it at adult hip operations suggests that it may often remain patent for much longer).

Nerve supply

The three nerves of the pelvic girdle and lower limb supply the hip joint (Hilton's law). The femoral nerve via the nerve to rectus femoris, the sciatic via the nerve to quadratus femoris, and the obturator nerve directly from its anterior division all innervate the capsule and retinacular fibres.

Movements

Examine a hip bone with its own femur. As in any ball and socket joint, movement is possible in any direction. Flexion, extension, adduction and abduction are free; a combination of all four produces circumduction. In addition, medial and lateral rotation of the femur occur. It is essential to the understanding of movements at the hip that the presence of the *neck* of the femur should be constantly borne in mind. For the purpose of analysing the mechanics of hip movement it is permissible and desirable to picture the *neck* of the femur as lying *horizontal* and the *shaft* of the femur as lying *vertical*.

Any movement of the shaft of the femur is accompanied by a quite different movement of the neck and head, and in this respect the mechanics of hip and shoulder are dissimilar.

Flexion of the hip is a term used to denote flexion of the thigh; when the thigh is flexed upon the trunk the head of the femur rotates about a transverse axis that passes through both acetabula (Fig. 3.19). The muscles responsible for flexion are psoas major and iliacus, assisted by rectus femoris, tensor fasciae latae, sartorius and pectineus. Flexion is limited by the thigh touching the abdomen, or by tension of the hamstrings if the knee is extended; the normal range is about 120°.

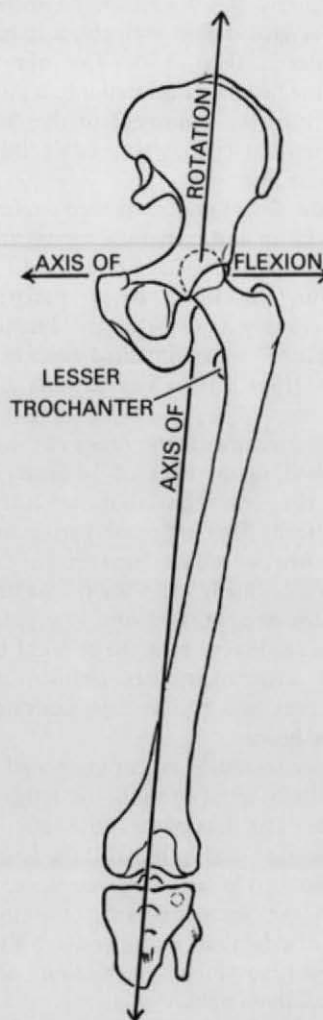


Fig. 3.19 Axes of rotation at the hip joint.

Extension of the thigh, the reverse of the above movement, is performed by gluteus maximus at the extremes of the movement and by the hamstrings in the intermediate stage. The movement is limited by tension in the iliofemoral ligament, and amounts to about 20°.

Adduction and abduction of the thigh produce similar movements in femoral shaft and neck; the femoral head rotates in the acetabulum about an anteroposterior axis. Adduction of about 30° is produced by contraction of the pectineus, adductors longus, brevis and magnus and the gracilis. It is limited by contact with the other leg or, if the latter is abducted out of the way, by the tension of gluteus medius and minimus (as in bending sideways on one leg). Abduction is produced by contraction of gluteus medius and minimus, assisted by piriformis. It is limited by tension in the adductors and in the pubofemoral ligament, and amounts to about 60°. Contraction of the abductors is essential in normal one-legged stance (see under gluteus medius and minimus, p. 164). It is important to note that when in the sitting (as opposed to the upright anatomical) position, piriformis and the gemelli and obturator muscles act as abductors, e.g. helping to move the leading leg on getting out of a car.

Rotation. Because of the orientation of the neck of the femur (see above), the femoral shaft does not rotate about its own axis (unless the neck of the femur is fractured), and in this respect it differs completely from the humerus. During rotation of the thigh the femoral neck swings backwards and forwards like a gate on its hinges, and the femoral head rotates in the acetabulum about a vertical axis as does a hinge. As the femoral neck swings to and fro, rotation of the femoral shaft occurs; forward movement of the neck produces medial rotation, and backward movement produces lateral rotation (Fig. 3.19).

It is easy to understand how muscles in the gluteal region, lying behind the joint and pulling the neck backwards, can cause *lateral rotation* of the femur; piriformis, obturator internus and the gemelli, quadratus femoris and obturator externus can all do this, assisted by the strong gluteus maximus overlying them. *Medial rotation* is more of a problem. It has long been believed that psoas and iliacus, passing in front of the joint to their attachments on the back of the femur, pull the neck forwards and so produce medial rotation, but *electromyography does not support this view*. It is the more anterior fibres of gluteus medius and minimus that have been confirmed as medial rotators, assisted by adductors and tensor fasciae latae. Acting from a fixed femur, the glutei of one side not only prevent drooping

of the pelvis to the opposite side during walking but also produce the forward movement of the opposite side of the pelvis when the leg of that side is swinging forward (thus acting as lateral rotators of the pelvis instead of medial rotators of the femur). It is possible that this pelvic movement is assisted by the oblique abdominal muscles, acting on the trunk through their thoracic attachments (p. 300), so supplementing the glutei whose muscle bulk is not very great.

If the neck of the femur is *fractured*, the shaft is free to rotate about its own axis, and psoas and iliacus (no doubt assisted by adductors attached to the linea aspera) produce the *lateral rotation* of the limb that is the characteristic feature of a fractured femoral neck.

Stability

The snug fit of the femoral head into the acetabulum, deepened by the labrum, makes the hip a very stable joint, further reinforced by the ligaments on the outside of the capsule, especially the iliofemoral. The short muscles of the gluteal region are important muscular stabilizers. The role of gluteus medius and minimus (and tensor fasciae latae, p. 164) when weight-bearing on one leg (as in walking) is all-important; they act not as abductors but as preventers of adduction, preventing the pelvis from tilting down on the opposite side when the opposite limb is off the ground. The joint is least stable when flexed and adducted; dislocation requires considerable force and may occur, for example, in serious car accidents.

Surgical approach

The hip joint can be approached from the front, side or back. From the front and side the routes lie in front of, through or behind tensor fasciae latae. The anterior approach is through the interval between sartorius and tensor fasciae latae, detaching the tensor, rectus femoris and the anterior parts of gluteus medius and iliacus from the hip bone so that the upper and anterior parts of the joint capsule can be reached. The anterolateral approach is between tensor fasciae latae and gluteus medius, exposing the capsule under the anterior borders of gluteus medius and minimus, detaching if necessary the reflected and straight heads of rectus femoris. The ascending branches of the lateral circumflex femoral vessels are hazards deep to the tensor and gluteus medius. The posterior approach involves splitting the middle of gluteus maximus in the line of its fibres. Piriformis, obturator internus and the

gemelli are divided at their femoral attachments to display the capsule. The sciatic nerve is retracted medially and is protected by turning the cut ends of obturator internus and the gemelli backwards over the nerve.

Needle *puncture* of the joint can be carried out from the front or side. At the front the needle is inserted 5 cm below the anterior inferior iliac spine and directed upwards, backwards and medially. For the lateral approach the needle passes in front of the greater trochanter and parallel with the femoral neck, entering the capsule through the lower ends of gluteus medius and minimus.

PART 4

POSTERIOR COMPARTMENT OF THE THIGH

The posterior or hamstring compartment of the thigh extends from the buttock to the back of the knee. It is separated from the anterior compartment by the lateral intermuscular septum, but there is no septum dividing it from the medial or adductor compartment, for the adductor magnus is a muscle consisting of fused flexor and adductor components.

The **cutaneous nerve supply** is by the posterior femoral cutaneous nerve (S2; p. 165), which runs vertically downwards just beneath the fascia lata to end halfway down the calf. It sends a series of perforating branches through the fascia lata to supply it and the overlying skin.

The *fascia lata* is relatively thin at the upper part, but is thickened and strengthened over the popliteal fossa by transverse fibres.

The hamstring muscles all arise from the ischial tuberosity and are inserted into the tibia or fibula; they thus span both the hip and knee joints. They are the semimembranosus, semitendinosus and biceps femoris (long head). The sciatic nerve, which supplies them from its tibial part, descends deep to them. The ischial fibres of adductor magnus which descend to the adductor tubercle but which in many mammals continue to the tibia, becoming degenerate in the human as the tibial collateral ligament, could also be considered a part of the hamstrings and, like them, are supplied by the sciatic nerve. However, the short head of biceps arises from the back of the femur and so does not span the hip joint; it is therefore not a true hamstring.

HAMSTRING MUSCLES

Semimembranosus

This extends from the ischial tuberosity to the medial condyle of the tibia. It arises from a smooth facet on the lateral part of the ischial tuberosity (Fig. 3.20), above the part that bears weight in sitting. It derives its name from the fact that this origin is a long flat tendon, or 'membrane', that extends down from the ischial tuberosity for 15 cm (6 in). The tendon is rounded on its lateral margin, sharp at its medial margin, so that it resembles a hollow-ground razor. In cross-section through the amputated thigh its appearance is very characteristic (Fig. 3.8). In wounds below the buttock the tendon provides a very useful landmark, for a finger's breadth from its lateral margin the sciatic nerve lies on the adductor magnus, deep to the long head of the biceps (Fig. 3.21). The flat tendon passes deep to semitendinosus and the long head of biceps, and muscle fibres commence to arise from its sharp medial edge some 15 cm (6 in) below the ischial tuberosity. Below this level the whole tendon is soon replaced by a bulky belly on the surface of which the cord-like tendon of semitendinosus lies. The muscle belly is replaced just behind the medial condyle of the femur by a strong cylindrical tendon which is inserted into the horizontal concavity on the back of the medial condyle of the tibia (p. 225). From this insertion three expansions diverge. One passes forwards along the medial surface of the condyle beneath the posterior free border of the tibial collateral ligament of the knee, separated from it by a bursa. A second expansion passes obliquely upwards as the oblique popliteal ligament (p. 180), while the third forms a strong fascia overlying popliteus and reaches the soleal line of the tibia.

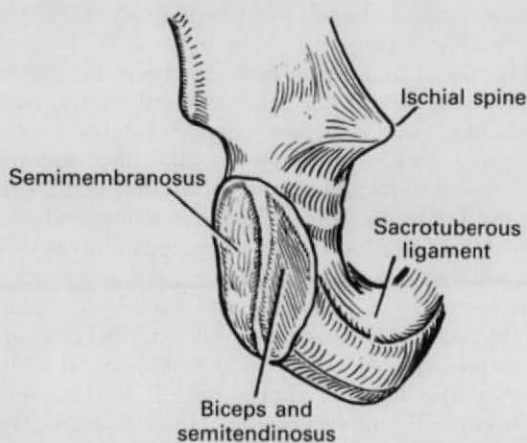


Fig. 3.20 Left ischial tuberosity, from behind.

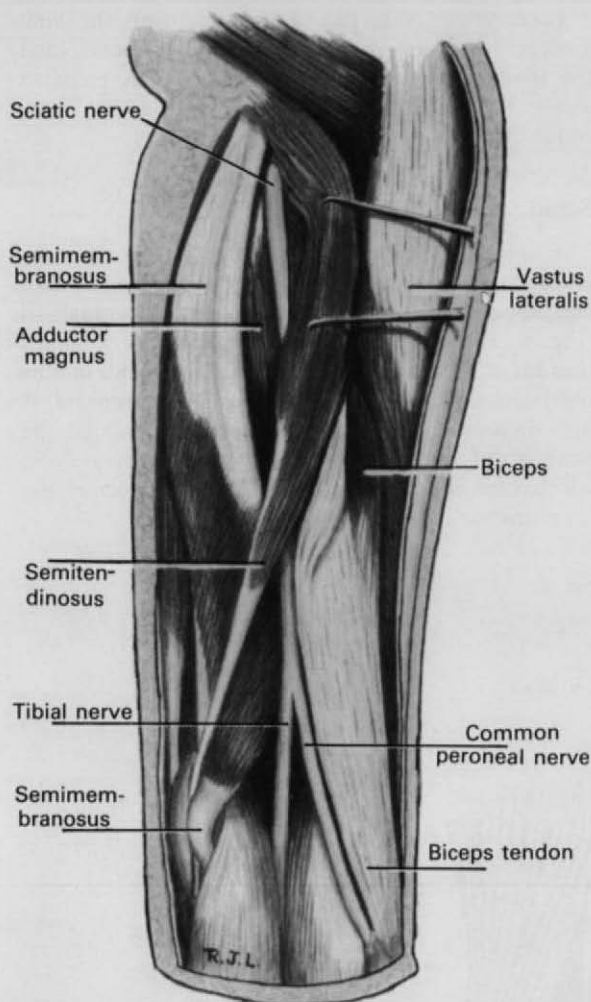


Fig. 3.21 Right hamstring muscles. Semitendinosus is retracted laterally to show the sciatic nerve lying on adductor magnus lateral to the tendinous upper end of semimembranosus.

Semitendinosus

This arises, in common with the long head of biceps, from the medial facet on the ischial tuberosity (Fig. 3.20). The fleshy belly diminishes in size from above downwards; it lies on the flat tendon of origin of semimembranosus. The semitendinosus is well named, for halfway down the thigh its belly gives place in a rather V-shaped manner to a cord-like tendon that lies in a reciprocal gutter on the surface of the muscular belly of semimembranosus.

The fleshy belly of each muscle lies against the tendon of the other, so that together they form a cylin-

drical mass. The tendon of semitendinosus passes behind the medial condyle of the femur and then curves forwards as it descends to the tibia, being inserted behind gracilis into the upper part of the subcutaneous surface of the tibia.

Biceps femoris

This muscle is so named because it possesses two heads of origin. The *long head* arises, in common with semitendinosus, from the medial facet on the ischial tuberosity (Fig. 3.20). It passes down to be joined by the short head. This has a long origin, from the whole length of the linea aspera and from the upper part of the lateral supracondylar line of the femur above the superior lateral genicular artery. The origin of the *short head* is by an aponeurosis which is rapidly replaced by muscle fibres that slope steeply downwards to fuse with the long head. The single tendon so formed is inserted into the head of the fibula in front of the styloid process (Fig. 3.29B) and across the tibiofibular joint to encroach a little on the condyle of the tibia. The tendon, at its insertion, is folded around the fibular collateral ligament of the knee joint (Fig. 3.30A).

Blood supply of the hamstrings. The hamstring compartment receives its blood supply mainly from the profunda femoris artery by way of the four perforating branches. These pierce the adductor magnus and give off large branches to the hamstrings and the overlying fat and skin, then pass laterally through the lateral intermuscular septum to end in the substance of vastus lateralis. The blood supply of the upper part of the hamstrings is derived from the inferior gluteal artery, that of the lower part from the popliteal artery. These and the perforating branches of the profunda femoris form a series of anastomoses along the back of the femur by means of their terminal arterioles. The highest is the cruciate anastomosis, in the buttock.

Nerve supplies. These three muscles of the flexor compartment of the thigh are supplied, with the ischial part of adductor magnus, by the tibial component of the sciatic nerve (L5, S1), the nerve of the flexor compartment. There is an exception in the case of the short head of biceps, which is supplied by the common peroneal (fibular) part of the sciatic nerve, the nerve of the extensor compartment of the leg, but the segments are the same (L5, S1). The explanation is that the short head of biceps was developed in the extensor compartment but migrated to the flexor compartment for functional reasons, retaining its nerve supply.

Actions. The hamstrings are essentially the flexor muscles of the knee joint, but they also have an extensor action on the hip joint, which is especially important in walking. When the knee is held extended by the contracting quadriceps the hamstrings extend the hip, particularly when the position of the hip joint is intermediate between full flexion and full extension. At the extreme ranges of hip movement, as in running, the extensor action of the hamstrings is enhanced by gluteus maximus. Note that the two 'semi' muscles are inserted medially and the two heads of the biceps laterally into the upper part of the leg. When the knee is flexed the alternate contraction of these muscles produces rotation at the knee joint. The 'semi' muscles are medial rotators, the biceps is a lateral rotator of the tibia on the femur. On the weight-bearing tibia the 'semi' muscles produce lateral rotation of the flexed femur, while the two heads of the biceps rotate the femur medially.

Test. While lying face downwards with the limb straight, the knee is flexed against resistance, and the tendons of biceps and semitendinosus palpated above the knee on the lateral and medial sides respectively.

Sciatic nerve

The **sciatic nerve** runs vertically through the hamstring compartment, lying deep to the long head of biceps, between it and the underlying adductor magnus (Fig. 3.23). At the apex of the popliteal fossa, a hand's breadth or more above the knee joint, it divides into its tibial and common peroneal (fibular) components. A high division is not at all uncommon and, indeed, the two parts of the nerve may leave the pelvis separately, in which case the common peroneal nerve pierces the lower margin of the piriformis.

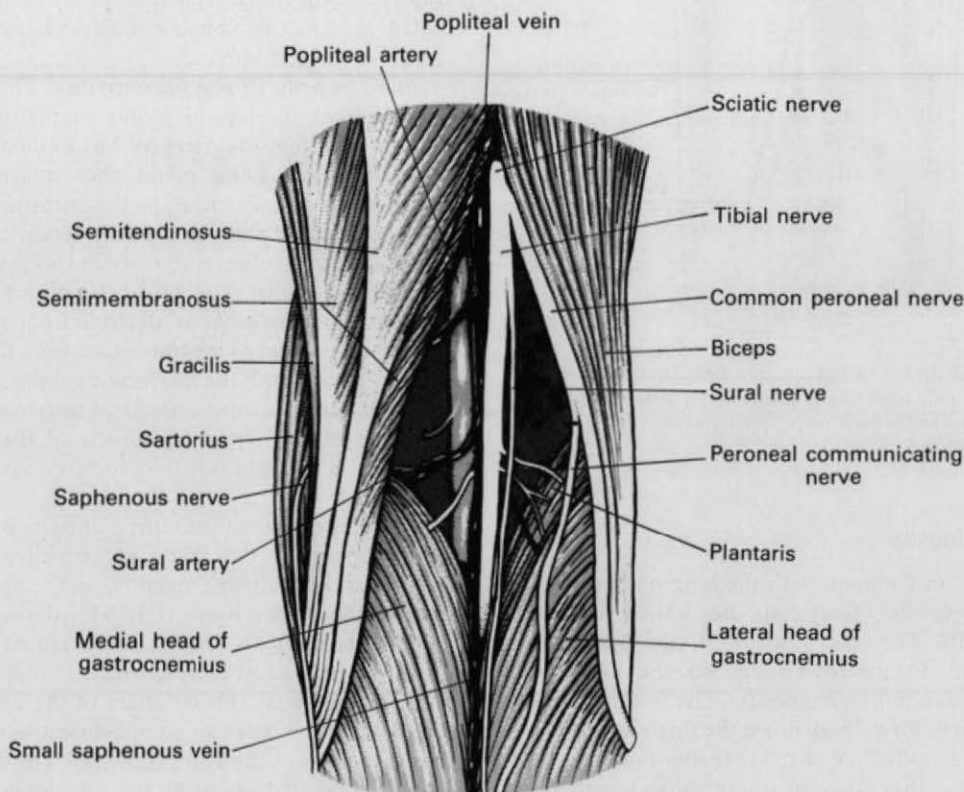


Fig. 3.22 Right popliteal fossa. Of the major neurovascular structures the tibial nerve is the most superficial and the popliteal artery the deepest, with the popliteal vein in between. The common peroneal nerve runs down behind the biceps tendon.

The *surface marking* of the nerve is from the midpoint between the ischial tuberosity and greater trochanter to the apex of the popliteal fossa.

The nerve supplies the semimembranosus, semitendinosus, part of adductor magnus and the long head of the biceps from its tibial portion, the short head of biceps from its common peroneal portion. The sciatic nerve is supplied with blood by a branch from the inferior gluteal artery; this *artery of the sciatic nerve* represents the remnant of the original axial artery of the limb and it may persist as a large vessel.

PART 5

POPLITEAL FOSSA AND KNEE JOINT

The **popliteal fossa** is a diamond-shaped space behind the knee (Fig. 3.22). It is limited above by the diverging semimembranosus and the semitendinosus on the medial side and the tendon of biceps on the lateral side.

In the living, the back of the flexed knee is hollow between the ridges made by the tensed hamstring tendons. In the extended knee the hamstring tendons lie against the femoral condyles and the fat of the popliteal space bulges the roof of the fossa.

The lower part of the 'diamond' is occupied by the heads of the gastrocnemius and is opened up only when they are artificially separated. The *roof* of the fossa is formed by the fascia lata, which is here strongly reinforced by transverse fibres. It is pierced by the small saphenous vein and the posterior femoral cutaneous nerve. The *floor* is provided, from above downwards, by the popliteal surface of the femur (the area between the medial and lateral supracondylar lines), the capsule of the knee joint and the popliteus muscle covered by its fascia. The popliteal artery and vein and the tibial and common peroneal nerves pass through the fossa. A small group of popliteal lymph nodes lie alongside the popliteal vein.

When examining a dissected popliteal fossa (Fig. 3.22) the surest way to distinguish right from left is to observe the common peroneal nerve emerging superficially across its lower *lateral* boundary. But do not mistake the tendon of semitendinosus on the medial side for the common peroneal nerve on the lateral side!

The **common peroneal nerve** (also known, like other 'peroneal' nerves and vessels, as the *common fibular nerve*) slopes downwards medial to the biceps tendon (where it is easily palpable in the living) and

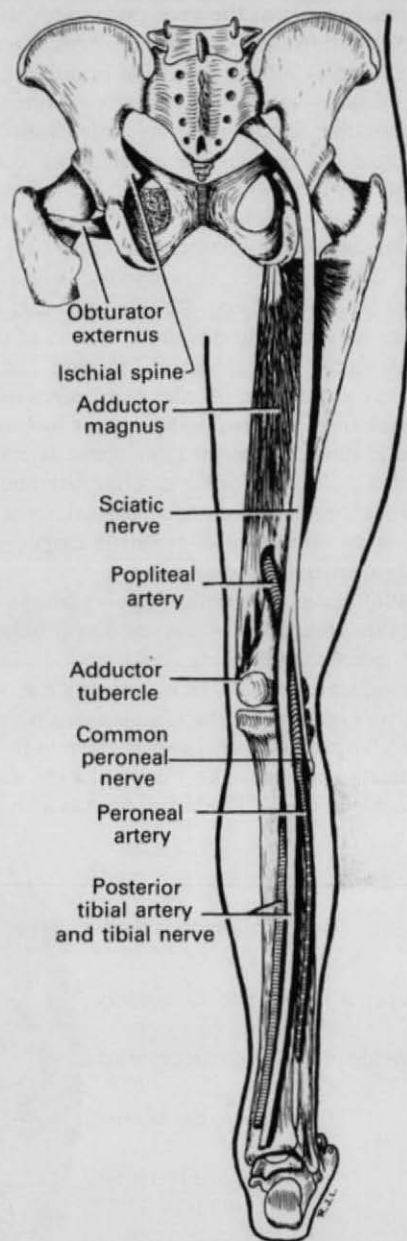


Fig. 3.23 Right sciatic, tibial and common peroneal nerves. The relations of the popliteal and posterior tibial arteries to the nerves are shown. The popliteal and posterior tibial veins have been removed; at all levels they lie between artery and nerve.

disappears into the substance of peroneus longus to lie on the neck of the fibula, against which it can be rolled in the living (confirm this on yourself). It lies successively upon plantaris, the lateral head of gastroc-

nemius, the capsule of the knee joint (with the popliteus tendon within) and the fibular origin of soleus. In its course it gives off the following branches: (1) the *peroneal (fibular) communicating nerve* which pierces the roof of the fossa and runs downwards in the subcutaneous fat to join the sural nerve below the bellies of gastrocnemius; (2) the *lateral cutaneous nerve* of the calf, which pierces the roof of the fossa over the lateral head of gastrocnemius and supplies skin over the upper part of the peroneal and extensor compartments of the leg; (3) superior and inferior *genicular nerves* which travel with the arteries of the same name and supply the capsule of the knee joint on its lateral aspect and, finally; (4) the *recurrent genicular nerve* which arises in the substance of peroneus longus, perforates tibialis anterior (supplying its upper lateral fibres) and supplies the capsule of the superior tibiofibular joint and the knee joint. The common peroneal nerve ends by dividing, in the substance of peroneus longus, into the deep and superficial peroneal nerves.

The **tibial nerve** runs vertically down *along the middle of the fossa* and disappears by passing deeply between the heads of gastrocnemius (Figs 3.21 and 3.22). If the latter are separated the nerve is seen passing, with the popliteal vessels, beneath the fibrous arch in the origin of soleus (compare with the median nerve in the cubital fossa passing beneath the fibrous arch in flexor digitorum superficialis). Below this fibrous arch it enters

the calf. The nerve gives *motor branches* to all the muscles that arise in the popliteal fossa, namely, to plantaris, both heads of the gastrocnemius, soleus, and popliteus. The last branch hooks around the lower border of popliteus to enter its deep (tibial) surface.

The tibial nerve here has only one cutaneous branch, the *sural nerve*. It runs vertically down in the narrow chink between the two heads of gastrocnemius and pierces the deep fascia halfway down the calf, where it replaces the posterior cutaneous nerve of the thigh. Passing down in the subcutaneous fat it joins the peroneal communicating nerve below the bellies of gastrocnemius where it is always close to the small saphenous vein which is the guide to the nerve (it can be used for grafts); the nerve is usually lateral to the vein.

Articular branches, the *genicular nerves*, are three in number. They accompany the superior and inferior medial genicular arteries to supply the medial ligament and medial part of the capsule of the knee joint, and the middle genicular artery to pierce the oblique popliteal ligament and supply the cruciate ligaments.

Popliteal vessels

Throughout the whole of its course the **popliteal artery** is the deepest of the large neurovascular structures in the fossa (Figs 3.23 and 3.24). It extends from

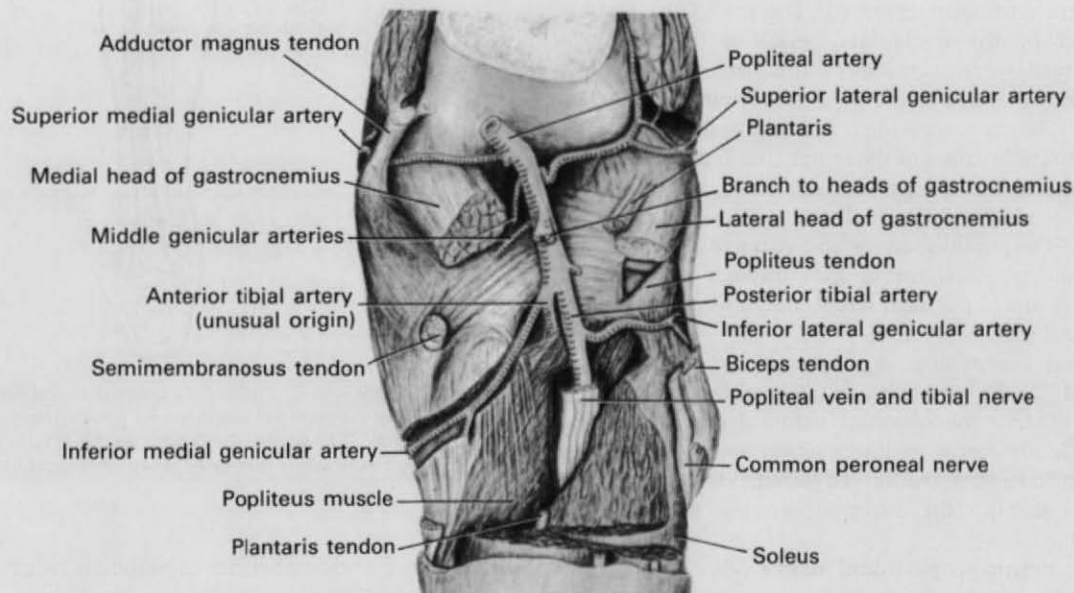


Fig. 3.24 Right popliteal and genicular arteries. In this specimen the anterior tibial artery has a high origin and passes deep to popliteus; it normally arises at the lower border of the muscle.

the hiatus in adductor magnus (a hand's breadth above the knee) to the fibrous arch in soleus (a hand's breadth below the knee) and is about 20 cm (8 in) long. It enters the fossa on the medial side of the femur; there it lies not only deep but medial to the sciatic nerve and its vertical continuation the tibial nerve (Fig. 3.23). As it passes downwards it is convex laterally, coming to lie lateral to the tibial nerve. Below the fibrous arch in soleus, as the posterior tibial artery, it returns to the medial side of the nerve (Fig. 3.23). At all levels the popliteal vein lies between the artery and the nerve. The artery lies at first on the popliteal surface of the femur, separated from it by a little cellular fat, then on the popliteal ligament of the knee joint to which it is firmly fixed by some overlying fibrous tissue and by the short middle genicular artery and, below this, it lies free on the fascia over the popliteus muscle. It passes under the fibrous arch in soleus and immediately divides into anterior and posterior tibial arteries. In the fetus the vessel passes between the popliteus

muscle and the tibia and this condition may persist in the adult (Fig. 3.24).

Being so deeply placed, detection of *popliteal pulsation* is not easy but is best felt with the knee partially flexed, using both hands with the thumbs on the patella and the fingertips pressing into the centre of the fossa.

Muscular branches are given to the muscles in the popliteal fossa; those to the two heads of gastrocnemius, the *sural arteries*, may arise from a common trunk. They are important because they are end-arteries and, if severed, there will be ischaemic necrosis of the heads supplied. The **genicular arteries** are five in number, upper and lower, lateral and medial and a middle (Figs 3.24 and 3.25). The medial and lateral upper genicular arteries encircle the lower end of the femur, the medial and lateral lower arteries encircle the tibia, while the *middle genicular artery* pierces the posterior ligament of the knee joint to supply the cruciate ligaments. The genicular branch of the posterior division of the obturator nerve (p. 161), having travelled

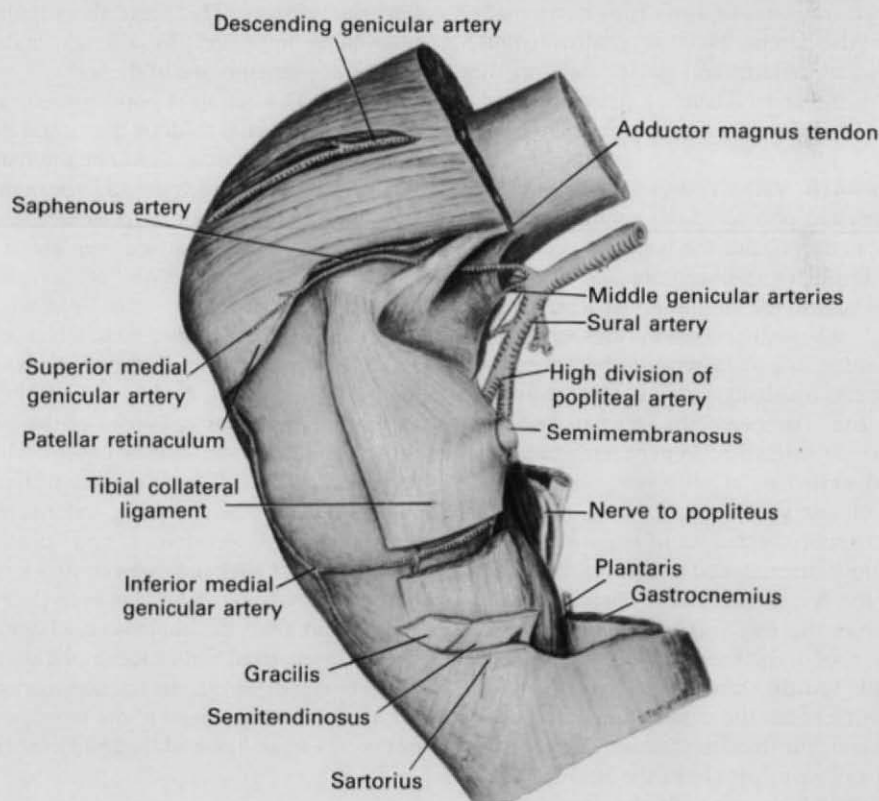


Fig. 3.25 Right knee from the medial side, showing the medial genicular arteries and the tibial collateral ligament. Part of the ligament has been removed to display the inferior medial genicular artery.

with the popliteal artery, enters the capsule alongside the middle genicular artery.

The *upper medial genicular artery* passes obliquely upwards across the medial head of gastrocnemius and crosses the medial supracondylar line deep to the tendon of adductor magnus superior to the upper attachment of the medial ligament of the knee.

The *upper lateral genicular artery* crosses the lateral head of gastrocnemius and passes upwards to cross the lateral supracondylar line just beneath a small tubercle that marks the lower limit of attachment of the short head of biceps femoris and the lateral intermuscular septum, and superior to the upper attachment of the lateral ligament of the knee. The two upper genicular arteries anastomose over the front of the femur and patella with the descending branch of the lateral femoral circumflex artery and the deep branch of the descending genicular (anastomotica magna) artery, and, over the front of the tibia, with the two lower genicular arteries.

The *lower medial genicular artery* courses obliquely downwards under the medial head of gastrocnemius and passes forwards, beneath the medial ligament of the knee. The *lower lateral genicular artery* runs horizontally outwards under the lateral head of gastrocnemius, crosses the popliteus tendon and passes deep to the lateral ligament of the knee. Thence it passes forwards *lying upon the lateral meniscus* of the knee joint (Fig. 3.24).

Surgical approach. Various surgical approaches to the popliteal artery are possible: from behind, carefully avoiding the major nerves and the popliteal vein; from the lateral side, through the fascia lata and displacing biceps backwards behind the intermuscular septum; and from the medial side, either behind the tendon of adductor magnus after displacing sartorius backwards, or lower down between (medially) semimembranosus and semitendinosus and (laterally) the medial head of gastrocnemius, which is detached from its femoral origin.

The **popliteal vein** lies, at all levels, between the artery and the tibial nerve (Fig. 3.22). It is formed by union of the two venae comitantes of the anterior and of the posterior tibial arteries, and it receives tributaries that accompany the branches of the popliteal artery. In addition, it receives the *small saphenous vein* (p. 192) which pierces the roof of the fossa.

The **popliteal lymph nodes** consist of a few scattered nodes lying about the termination of the small saphenous vein, beneath the deep fascia. They receive from a small area of skin just above the heel by a few superficial afferents which run with the small saphenous vein and pierce the roof of the fossa, and from the deep structures of the calf by deep afferents that accompany the posterior tibial vessels. They send their effer-

ents alongside the popliteal and femoral vessels to the deep inguinal nodes.

Popliteus

The fleshy fibres of this muscle (Fig. 3.26) arise from the popliteal surface of the tibia above the soleal line and below the tibial condyles. The muscle slopes upwards and laterally towards the cord-like tendon, which is attached to a pit just below the epicondyle on the lateral surface of the lateral condyle of the femur. The tendon lies within the capsule of the knee joint, entering it beneath a falciform free edge, the *arcuate popliteal ligament*, to which the superficial fibres of the muscle are attached (Fig. 3.26). Only half of the popliteus muscle continues into this tendon; the upper half of the muscle ends in a short flat tendon which is *inserted into the posterior convexity of the lateral meniscus* (Fig. 3.29). The popliteus bursa lies deep to the tendon, where the tibia is grooved.

Nerve supply. By a branch of the tibial nerve which winds around its lower border and sinks into its deep (anterior) surface. This nerve also supplies the superior tibiofibular joint and, by a long slender branch, the interosseous membrane of the leg.

Action. The action of popliteus is to rotate the knee and simultaneously to draw the lateral meniscus posteriorly. In the fully extended knee the femur has rotated medially on the tibia to 'lock' the joint. The femur, from the extended position, is rotated laterally by popliteus to 'unlock' the joint. Further lateral rotation of the femur involves excursion of its lateral condyle backwards across the tibial plateau. The lateral meniscus is pulled backwards in advance of the femoral condyle by contraction of the popliteus. The posterior margin of the lateral condyle of the tibia is rounded off, so that the posterior convexity of the lateral meniscus can be pulled down over it out of harm's way. The mobile lateral meniscus, its position thus controlled by the popliteus, is therefore relatively immune to impaction between femur and tibia. The medial meniscus lacks such muscular control and is more liable to rupture by being caught between the two bones.

To summarize, the popliteus is a lateral rotator of the femur on the fixed tibia and simultaneously a retractor of the lateral meniscus. Its femoral tendon is attached at the axis of the hinge joint of the knee; consequently it is not even a weak flexor of the knee joint (p. 183).

KNEE JOINT

The **knee joint** is a synovial joint between femur and tibia, with the patella also articulating with the femur at

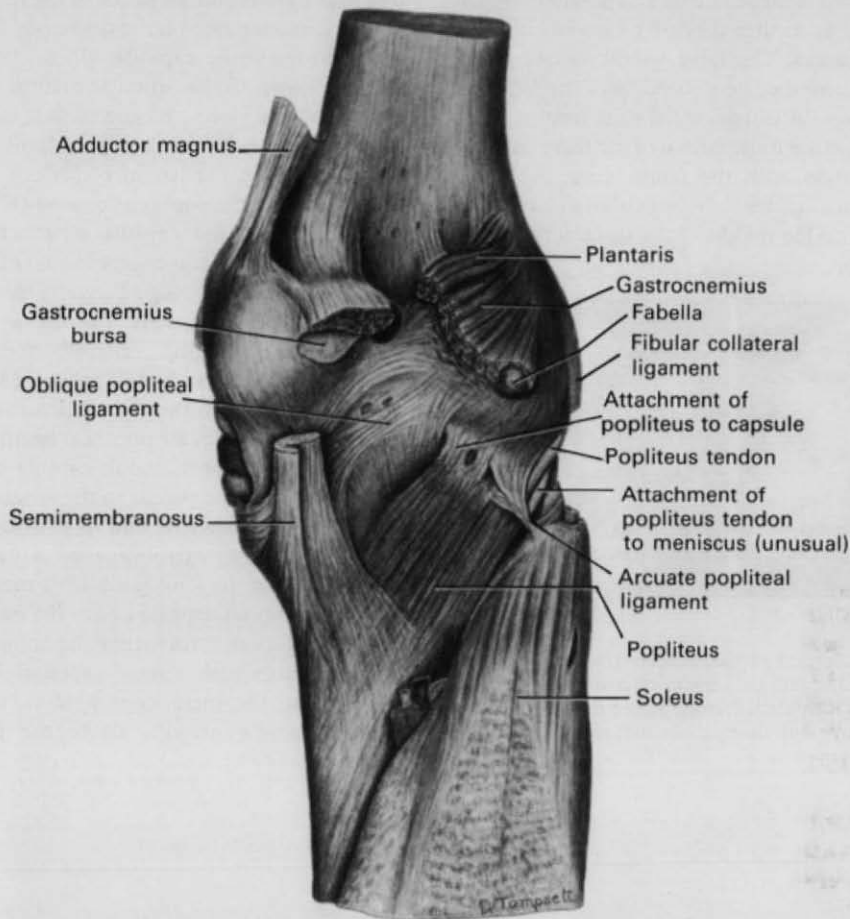


Fig. 3.26 Right knee joint from behind, showing the reinforcement of the capsule by the oblique popliteal ligament, and popliteus emerging from the capsule. The fabella is a sesamoid bone sometimes present in the lateral head of gastrocnemius.

the front. Although the joint can flex and extend like a hinge, the geometry of the surfaces is complex and to liken the hinge to that of a box or door is a gross oversimplification. Extension is for propulsion, and flexion is used prior to this and also to absorb the shock (by quadriceps) in landing. In addition the *flexed* knee can rotate, as in change of direction at speed. This active rotation is a matter of choice, and is not to be confused with the passive and inevitable rotation that occurs in straightening the knee in the 'screw-home' mechanism (p. 183). During all these movements the knee is adapted to be weight-bearing and stable in any position.

The upper surface or plateau of the *tibia* possesses two separate articular facets, each slightly concave (Fig. 3.58). The medial facet lies wholly on the upper

surface of the condyle, but the lateral facet becomes slightly convex at the back where it curves back over the posterior margin of the tibial condyle (Fig. 3.60). This bevelled margin allows withdrawal of the lateral meniscus by popliteus (p. 176). The *femur* has two condyles, separated posteriorly by a deep notch, but fusing anteriorly into a trochlear groove for articulation with the patella. The lateral ridge of the trochlear groove is very prominent (Fig. 3.11). The curve of the femoral condyles is cam-shaped (in lateral profile); it is flatter on the end of the femur and more highly curved at the free posterior margin of each condyle (Fig. 3.33). The distal surface of the medial condyle is narrower, longer and more curved than the lateral condyle (Fig. 3.11); this is for the screw-home movement (p. 176). The articular surface of the *patella* is divided by

a vertical ridge into a large lateral and a small medial surface; this latter is further divided by a vertical ridge into two smaller areas. The large lateral surface glides around *in contact with* the lateral condyle of the femur in all ranges of flexion. In extension the area next to it lies on the trochlea, and the most medial of the three surfaces is not in articulation with the femur (Fig. 3.27). In flexion this surface glides into articulation with the medial condyle, and the middle of the three surfaces lies

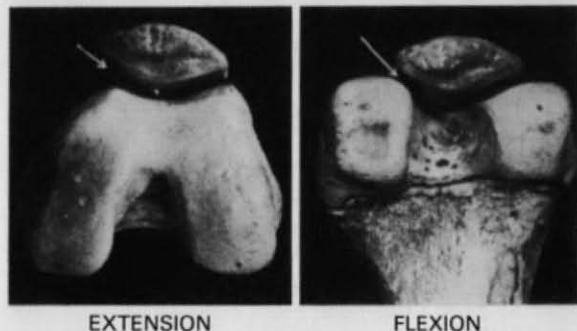


Fig. 3.27 Left femur and patella, as seen when looking upwards from the tibia with the knee in extension and flexion. The medial facet of the patella (arrow) is free in extension but in flexion it articulates with the medial condyle of the femur.

free in the intercondylar notch of the femur. This can be readily demonstrated on the dry bones.

On the *femur* the **capsule** adheres below the epiphyseal line down to the articular margin (Fig. 1.8, p. 11) except in two places. At the back it is attached to the intercondylar ridge at the lower limit of the popliteal surface, and on the lateral condyle it encloses the pit and groove for the popliteus tendon (Fig. 3.33).

On the *tibia* the capsule is attached around the margins of the plateau except in two places. Posteriorly it is attached to the ridge between the condyles at the lower end of the groove for the posterior cruciate ligament (Fig. 3.30B). Laterally the capsule is not attached to the tibia but is prolonged down over the popliteus tendon to the styloid process on the head of the fibula as the arcuate popliteal ligament (see below).

The thickness of the adult capsule varies. From the lower margin of the patella to the anterior margin of the plateau of the tibia it is thin. It is invaginated together with the synovial membrane by a pad of fat whose herniation into the joint raises up a median *infrapatellar fold*. The original capsule above the patella, between it and femur, perforates when the infant walks and so communicates with a large suprapatellar bursa which lies deep to the quadriceps tendon, extending in the adult a hand's breadth above the joint. Thus the

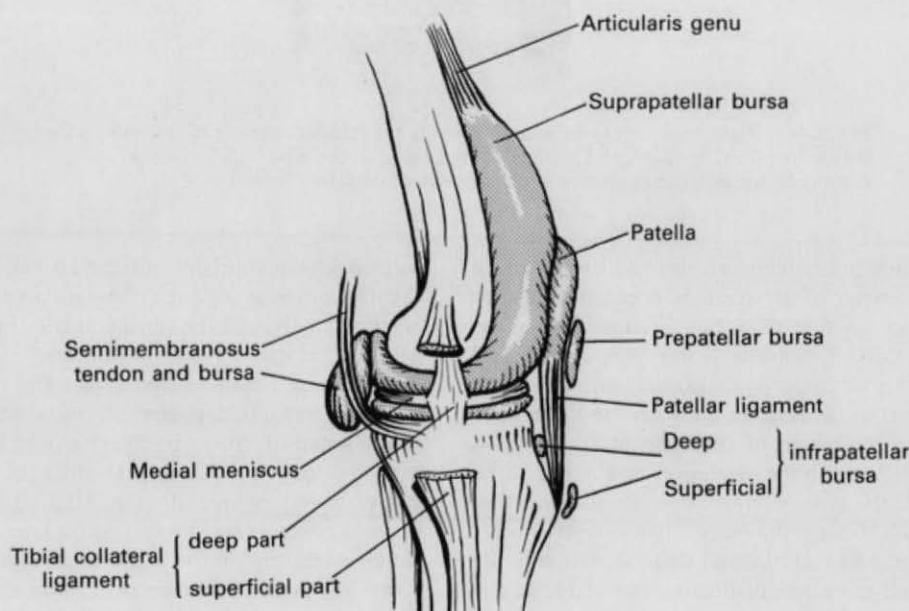


Fig. 3.28 Left knee joint from the medial side, showing the position of bursae (here distended for clarity). The superficial part of the medial ligament has been incised and reflected to show the deep part.

capsule has two *main* gaps in it, the one allowing popliteus tendon to enter, the other communicating with the suprapatellar bursa. Anteriorly the capsule is interrupted by a circular gap whose margins are attached to the patella.

On the medial side part of the capsule is thickened to form the deep part of the medial ligament (formerly known as the short internal lateral ligament; see below); it is firmly attached to the medial meniscus (Figs 3.28, 3.29B and 3.30B). On the lateral side a much less marked thickening (formerly known as the short external lateral ligament) may occur under the lateral ligament, but such a thickening here is frequently absent and it has no official name. Elsewhere around the convexity of both menisci the capsule, attached to the femur above and tibia below, is thin and lax and sometimes known here as the coronary ligament (another unofficial name).

The **ligaments** (apart from the capsule) can be classified as extracapsular and intra-articular. The

extracapsular ligaments include the patellar retinacula and the patellar, tibial collateral and fibular collateral, and the oblique popliteal ligaments. The intra-articular ligaments include the anterior and posterior cruciate ligaments and the medial and lateral menisci, with which are associated the transverse and meniscomfemoral ligaments. Most of the tendon of popliteus is also intra-articular, though not a joint ligament in the strict sense. This tendon and the cruciate ligaments, although intra-articular (intracapsular) are extrasynovial.

The **patellar retinacula** extend from the patella to the lower margins of the condyles of the tibia; they are fibrous expansions from the quadriceps tendon and from the lower margins of vastus medialis and lateralis. In front of the collateral ligaments they blend with the capsule; further anteriorly they are attached to the margins of the patellar ligament, below the patellar attachment of the capsule. They are, of course, not attached to the femur and *must not be confused with the capsule*. Deep to them lie the (extracapsular) fat pad

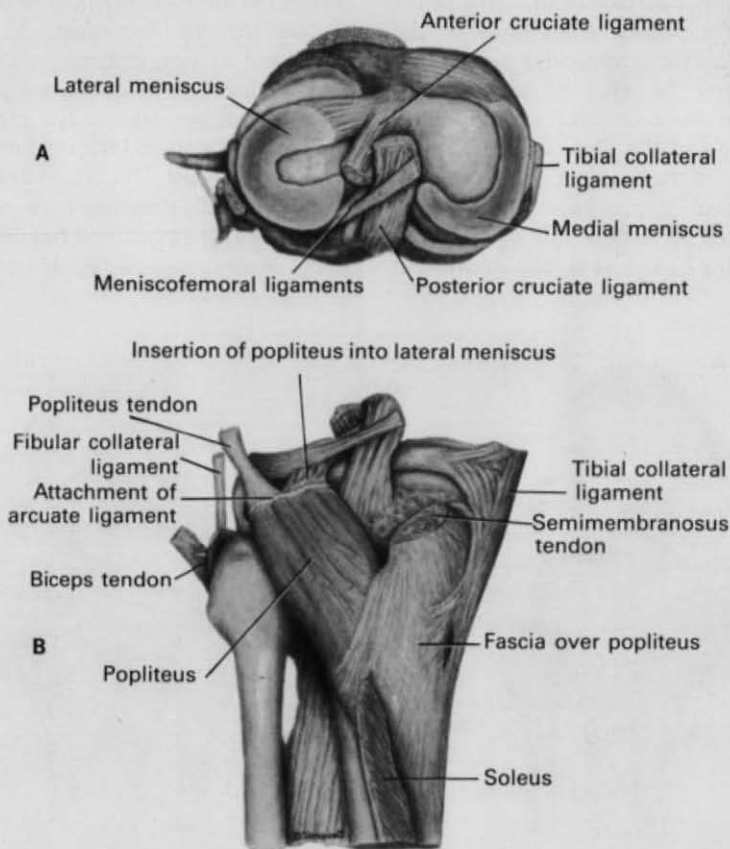


Fig. 3.29 Menisci of the left knee joint, A from above, B from behind.

and the deep infrapatellar bursa (Fig. 3.28). Below the patella the capsule is replaced by the very strong and dense patellar ligament which, by its attachment to the tibial tuberosity (Fig. 3.28), keeps the patella at a constant distance from the tibia.

The **tibial collateral ligament**, commonly and more simply called the medial ligament, consists of superficial and deep parts. The *superficial part* (Figs 3.25 and 3.28) is attached to the epicondyle of the femur below the adductor tubercle and to the subcutaneous surface of the tibia a hand's breadth below the knee. It is a broad, flat band of great strength, about 12 cm long. Its anterior margin lies free except at its attached extremities and is not attached to the medial meniscus, being separated from it and the condyle of the tibia by a bursa. Its *posterior* margins converge to be inserted into the medial meniscus; only these marginal fibres of the superficial part are attached to the meniscus (Fig. 3.30B). Over the condyle of the tibia the ligament is separated from bone by the forward extension from the semimembranosus tendon and the intervening bursa (Fig. 3.28). Below this, over the upper surface of the shaft of the tibia, the ligament is separated from bone by the passage of the inferior medial genicular vessels and nerve (Fig. 3.25). Hence the extension of the medial ligament so far below the knee joint to find a firm attachment; the condyle of the tibia is free to rotate beneath the upper part of the ligament. From its tibial attachment the ligament slopes back a little as it passes up to be inserted *behind* the axis of flexion of the femoral condyle (Fig. 3.28). It is thus drawn taut

by (and limits) extension of the knee and its terminal 'screw-home' rotation.

The *deep part* of the medial ligament is the thickening of the capsule referred to above by its old name of short internal lateral ligament; it still has no modern official name despite its importance. It is under cover of the superficial part and is attached above and below to the femur and tibia just beyond the articular margins and centrally to the periphery of the medial meniscus (Figs 3.28, 3.29A and 3.30B). At the front and back it is continuous with the rest of the capsule and so only has free anterior and posterior margins when artificially cut off from the capsule (as in Fig. 3.28). The lower meniscotibial part is usually less pronounced than the upper menisiofemoral part. The whole ligament is said to be the phylogenetically degenerate part of adductor magnus.

The **fibular collateral ligament**, commonly and more simply called the lateral ligament, is attached to the lateral epicondyle of the femur and slopes down and back to the head of the fibula. It lies free from the capsule and lateral meniscus (Fig. 3.30), being separated from the meniscus by the tendon of popliteus inside the joint and the inferior lateral genicular vessels outside the joint. It is round and cord-like, about 5 cm long, and so quite different in size and shape from the medial ligament. It is attached just behind the axis of flexion of the femoral condyle and is drawn taut by (and limits) extension and the terminal 'screw-home' movement of the knee. The whole ligament is said to be the phylogenetically degenerate part of peroneus longus.

The **oblique popliteal ligament** is a thick rounded band of great strength, perforated by the middle genic-

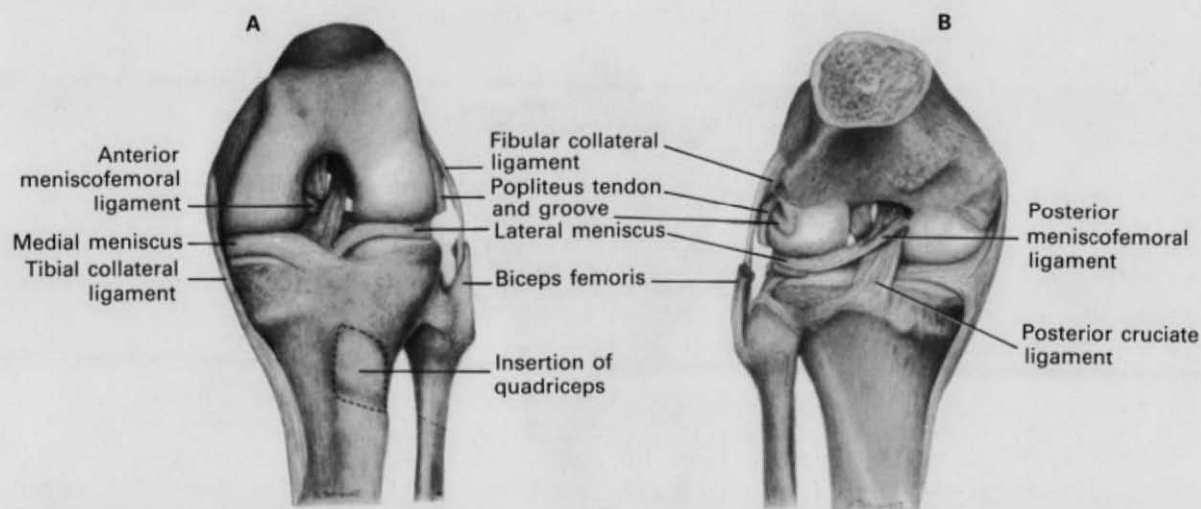


Fig. 3.30 Ligaments of the left knee joint, with the knee partially flexed. A from the front, B from behind.

ular vessels. It is a lateral expansion from the insertion of semimembranosus which slopes up to the popliteal surface of the femur (Fig. 3.26). It blends with the capsule above the lateral condyle of the femur, and in the intercondylar notch rather above its margin, so that a prolongation upwards of synovial membrane extends a little on the popliteal surface of the femur. Loose bodies may lodge here, behind the upper ends of the cruciate ligaments, and elude discovery at operation. The obliquity of this ligament limits rotation-extension in the 'screw-home' or locked position.

The **arcuate popliteal ligament** (Fig. 3.26) arches over the popliteus tendon as it emerges from the capsule, with some popliteus muscle fibres being attached to it. From its attachment to the styloid process of the head of the fibula it can be traced upwards to blend with the capsule, sometimes as far as the lateral condyle of the femur; other fibres join the part of popliteus that is attached to the lateral meniscus.

The **cruciate ligaments** consist of a pair of very strong ligaments connecting tibia to femur and they lie within the capsule of the knee joint, but not within the synovial membrane. It is as though they had been herniated into the synovial membrane from behind, carrying forward over themselves a fold which invests their anterior and lateral surfaces but leaves their posterior surfaces uncovered. They are named from their tibial origins (Fig. 3.29). The **anterior cruciate ligament** is attached to the anterior part of the tibial plateau in front of the tibial spine and extends upwards and backwards to a smooth impression on the *lateral* condyle of the femur well back in the intercondylar notch (Fig. 3.56). The **posterior cruciate ligament** is attached to the posterior part of the tibia between the condyles and from the very uppermost part of the adjacent *posterior* surface (Figs 3.29A, B and 3.30B), and passes forwards medial to the anterior cruciate ligament. It is attached to a smooth impression on the *medial* condyle of the femur well forward in the intercondylar notch (Fig. 3.56). The two cruciate ligaments cross like the limbs of the letter X. They are essential to the anteroposterior stability of the knee joint, especially in the flexed position. The role of each cruciate ligament must be studied separately.

The *posterior cruciate ligament* prevents the femur from sliding forwards off the tibial plateau (Fig. 3.31). In the weight-bearing flexed knee it is the *only* stabilizing factor for the femur and its attached quadriceps (popliteus is too weak to be of significant help). In walking downhill or downstairs the upper knee is flexed and weight-bearing while the lower knee is straight as its foot reaches down to find support. Thus with a

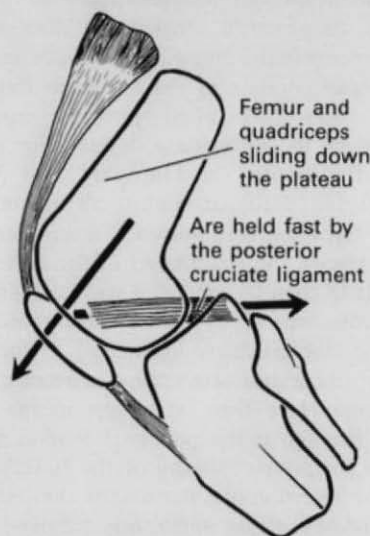


Fig. 3.31 Weight-bearing on the flexed knee. The body weight is suspended on the posterior cruciate ligament. This is the position of the upper knee during progression downhill.

ruptured posterior cruciate ligament the patient leads with the damaged leg at each downward step, keeping the weight-bearing knee extended.

The *anterior cruciate ligament* prevents backward displacement of the femur on the tibial plateau, but this is unlikely to happen. The anterior cruciate ligament has a much more important role, that of limiting extension of the lateral condyle of the femur and of then causing medial rotation of the femur in the 'screw-home' position of full extension. This is discussed on page 183.

The **menisci**, formerly called semilunar cartilages, are composed of fibrocartilage (like the glenoid and acetabular labra). They are basically C-shaped, triangular in cross-section and avascular except at their attachments. The **medial meniscus** (Fig. 3.29A) is the larger and is really more comma-shaped than C-shaped, with an open curve whose ends or horns enclose the horns of the lateral meniscus. The anterior horn of the medial meniscus (the narrow end of the comma) is attached to the intercondylar area of the tibia in front of the anterior cruciate ligament, while its broader posterior horn is similarly attached in front of the posterior cruciate. Its attachment to the medial ligament has been mentioned above.

The **lateral meniscus** (Fig. 3.29A) is more truly C-shaped and its horns are fairly close to one another, attached to the intercondylar area of the tibia immediately in front of and behind the intercondylar spine.

There is no fusion with the lateral ligament (Figs 3.29B and 3.30). Its posterior convexity is slung by fibrous tissue ligaments to the femur. These slings are attached to the medial condyle of the femur in front of and behind the attachment of the posterior cruciate ligament, forming the **anterior** and **posterior menisco-femoral ligaments** (of Humphry and Wrisberg) (Figs 3.29 and 3.30). In almost all mammals these ligaments form the sole posterior attachments of the lateral meniscus; the attachment of the posterior horn to the tibia in man is associated with upright posture. The circumference of the meniscus is attached by very lax capsule (the coronary ligaments) to the articular margins of femur and tibia except beneath the tendon of popliteus. Here there is a gap in the coronary ligament; through it the popliteus tendon and bursa pass. The posterior convexity of the lateral meniscus receives the insertion of a flat tendon derived from the *upper half of the popliteus muscle* (Fig. 3.29B).

The **transverse ligament** is a variable band that, when present, passes across between the anterior horns of the medial and lateral menisci. The delicate capsule is attached to it.

The menisci receive their nutrition from the surrounding synovial fluid; their only blood vessels are at the extreme periphery, coming in from the capsule.

The functions of the menisci are discussed below.

The femoral **tendon of popliteus** lies between the capsule and the synovial membrane. The tendon does not lie free within the cavity of the knee joint, but is adherent to the capsule. The adherent tendon makes a prominent ridge on the inner surface of the capsule. The ridge is invested with the synovial membrane of the joint cavity both above and below the lateral meniscus. Between the upper and lower synovial reflexions the bare lateral meniscus is in contact with the bare tendon of popliteus, and the meniscus is often grooved by the tendon. Occasionally the tendon is partly attached to the meniscus in the manner shown in Figure 3.26.

The knee is the largest synovial joint in the body, but the amount of synovial fluid in a normal joint is about 0.5 ml — a mere capillary film. The attachment of the **synovial membrane** does not coincide with the capsular attachments, because of the intra-articular structures. On the *femur* it lines the intercondylar notch and on the lateral condyle is separated from the capsule by the attachment of popliteus tendon, which lies between the two. That is to say, it is attached all around the articular margin of the femur. On the *tibia* it is attached to the articular margins of medial and lateral condyles, and is reflected forwards over the anterior cruciate ligament from these margins. A fold extending from here to the inferior margin of the patella is known

as the *infrapatellar fold*; an *alar fold* extends both medially and laterally from it. The infrapatellar fold and alar folds are produced by an extrasynovial fat pad and they adapt their shape to the contours of the bones in different positions of the knee. By keeping the synovial membrane in contact with the articular surfaces of the femoral condyles they act as Haversian fat pads (p. 12).

Communications with bursae characterize the synovial cavity of the knee joint. The communication with the suprapatellar bursa has already been noted. A herniation of synovial membrane beneath the rounded tendon of popliteus produces the banana-shaped *popliteus bursa* lying in the gutter between the tibia and the head of the fibula (Fig. 3.32). The bursa beneath the medial head of gastrocnemius always and that beneath the lateral head usually, communicate with the joint. The bursa under the medial head of gastrocnemius usually communicates also with the semimembranosus bursa (p. 170), thereby connecting the latter bursa with the cavity of the knee joint.

Blood supply

The capsule and joint structures are supplied from the anastomoses around the knee. The chief contributors are the five genicular branches of the popliteal artery, of

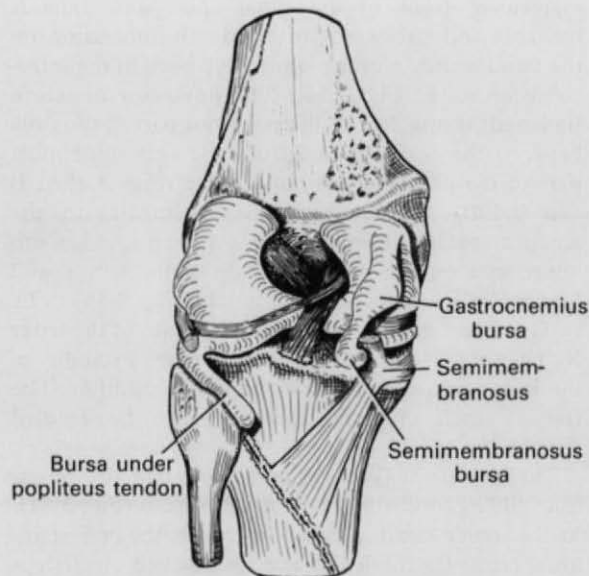


Fig. 3.32 Synovial membrane (distended) of the left knee joint, from behind. The semimembranosus bursa here communicates with the bursa under the medial head of gastrocnemius.

which the middle genicular supplies the cruciate ligaments.

Nerve supply

In accordance with Hilton's law the joint is supplied from the femoral, especially its branch to the vastus medialis, from the sciatic by the genicular branches of the tibial and common peroneal, and from the obturator nerve by the twig from its posterior division, which accompanies the femoral artery through the gap in the adductor magnus into the popliteal fossa. During arthroscopy it must be remembered that, although local anaesthesia affects the overlying skin, the cruciate ligaments remain sensitive (tibial nerve). The menisci are virtually devoid of sensory fibres.

Movements

The movements of the knee joint are flexion, extension and rotation. *Active* rotation is possible only in a flexed knee. The passive rotation that occurs in the 'screw-home' movement of full extension is something quite different. There is no active rotation of the extended knee.

Flexion is performed by the hamstrings and this is limited to about 150° by compression of the soft parts behind the knee. **Extension** is performed by the quadriceps and is limited by the tension of the anterior cruciate ligament, the oblique popliteal ligament and the collateral ligaments, but these four ligaments do not tighten simultaneously. As the knee moves into full extension the anterior cruciate ligament is the first to become taut. *Extension of the lateral condyle of the femur is thus terminated.* Further extension of the medial condyle is made possible by passive rotation forwards of the lateral condyle around the radius of the taut anterior cruciate ligament. This forces the medial condyle to glide backwards into its own full extension. The medial condyle has a longer and more curved articular surface than the lateral condyle for this very reason (Fig. 3.11). This **medial rotation** of the femur on the tibial plateau tightens the oblique popliteal ligament; the medial and lateral ligaments of the knee joint are set slightly obliquely and are tightened simultaneously. All three become taut and limit further rotation. This 'screw-home' movement is said to *lock the joint* and the description is just. In this position the joint is slightly hyperextended and all four ligaments are taut — the anterior cruciate preventing further extension and the other three also preventing further rotation. The knee is completely rigid. It must be emphasized that these rotatory movements, which may amount to 15° or so, are purely passive and result from the skew pull of the

obliquely set ligaments. They occur whether the extending force on the knee is active (quadriceps contraction) or passive, and have been shown radiologically to begin at a much earlier stage than the final 'screw-home'. The lowest fibres of vastus medialis (those attached at right angles to the side of the patella) are of the very greatest importance in obtaining the final degrees of complete extension (p. 157).

From the 'screw-home' or 'locked' position **lateral rotation** of the femur must precede flexion; this *lateral rotation is produced by the popliteus*. The 'untwisted' knee can now be flexed by the hamstrings.

In the flexed position all the above four ligaments are relaxed, and a smaller femoral surface articulates with the tibial plateau; thus *active rotation* is possible and is produced by biceps laterally and semimembranosus and semitendinosus medially. It is rotatory movements of the flexed knee that cause tears of the menisci.

The menisci are passively opened up in extension because a broader femoral condyle separates their anterior and posterior convexities (Fig. 3.33). Flexion and extension take place above the menisci, in the upper compartment of the joint. Rotation takes place below the menisci, in the lower compartment. The fact that the only mammal unable to rotate the knee (the fruit bat) is the only one to lack menisci and a popliteus muscle suggests that the menisci are associated with rotation, but the significance of this for the human knee is obscure. By their shape the menisci help to deepen slightly the tibial articular surfaces, like the glenoid labrum of the shoulder joint, and so perhaps play a small part in the stability of the joint. They also help to spread synovial fluid, but they are more important as shock-absorbers. They bear something like half the weight-bearing load in the upright position, distributing it over an area wider than that of the purely bony contact between the femur and tibia. The medial meniscus, being tethered to the medial ligament, is much less mobile than the lateral which, with its attachment to popliteus and to the femur by the menisco-femoral ligaments (Fig. 3.34) can get 'pulled out of the way', so it is not surprising that the medial meniscus is torn 20 times more often than the lateral.

Stability

Bony contours contribute nothing to the anteroposterior stability of the knee joint, but the spine of the tibia prevents sideways gliding of femur on tibia (try it on the dry bones!). The cruciate ligaments are indispensable to anteroposterior stability in flexion. Lateral stability and stability in extension are provided by the collateral and oblique popliteal ligaments. Muscle function is also

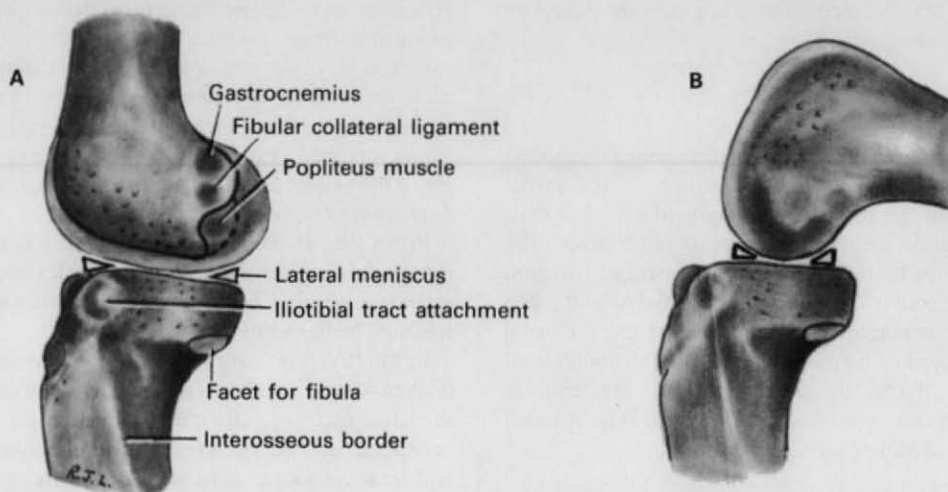


Fig. 3.33 Articular contours of the left knee joint, from the lateral side. **A** In extension, where the broader part of the femoral condyle separates the anterior and posterior parts of the meniscus. The heavy line indicates the attachment of the capsule, and the interrupted line the attachment of the synovial membrane; the tendon of popliteus intervenes. **B** In flexion, where the narrower part of the condyle causes less separation of the meniscus.

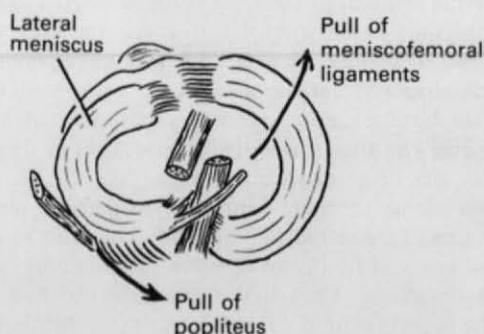


Fig. 3.34 Left tibia and menisci from above. When the femur rotates laterally on the fixed tibia, the forward movement of the medial femoral condyle pulls forwards on the meniscomfemoral ligaments, but forward movement of the lateral meniscus is prevented by the backward pull of popliteus.

vitaly important; the vasti by their expansions (the retinacula) contribute greatly, and vastus medialis assists in the stability of the patella (p. 157). The iliotibial tract (gluteus maximus and tensor fasciae latae) stabilizes the slightly flexed knee (p. 151).

Surgical approach

The knee joint can be widely exposed from the front on either side of the patella by incisions through the vasti and alongside the patella and its ligament. A more

limited approach to the medial meniscus with the knee flexed is along the medial side of the patella but with the incision extending no more than 1 cm below the upper margin of the tibia, to avoid damage to the infrapatellar branch of the saphenous nerve which curves forwards below this level. Exposure of the back of the joint capsule through the popliteal fossa involves opening up the interval between the tibial nerve and semimembranosus, then displacing the nerve and popliteal vessels laterally and detaching the medial head of gastrocnemius from its origin. This head is also displaced laterally, so revealing the capsule and helping to protect the vessels and nerve. The middle genicular artery will require ligation.

Aspiration is usually carried out from the side at the upper lateral margin of the patella, the needle entering the suprapatellar bursa. For injection the joint is entered at the lower border of the patella on either side of the patellar ligament. The needle tip must not damage the menisci or joint surfaces. For arthroscopy the approach is on the lateral side of the patellar ligament.

PART 6

ANTERIOR COMPARTMENT OF THE LEG

The front of the leg includes the subcutaneous surface

of the tibia on the medial side and the extensor muscular compartment on the anterolateral side.

The **cutaneous nerves** are derived from the femoral nerve over the tibia and from the common peroneal nerve over the extensor compartment (Fig. 3.52). The *saphenous nerve* gives off its infrapatellar branch to supply the subcutaneous periosteum of the upper end of the tibia and the overlying skin and then descends just behind the great saphenous vein, with which it passes in front of the medial malleolus. It usually bifurcates 5–7 cm above the malleolus, and the branches run on each side of the vein. The main nerve (anterior branch) ends on the medial side of the foot at the bunion region — the metatarsophalangeal joint. The *lateral cutaneous nerve* of the calf, a branch of the common peroneal, supplies deep fascia and skin over the upper parts of the extensor and peroneal compartments and the *superficial peroneal nerve* replaces it over the rest of these surfaces.

The subcutaneous surface of the tibia has subcutaneous fat attached to its periosteum; there is no deep fascia covering it. The great saphenous vein and the saphenous nerve lie in the fat, accompanied by numerous lymphatic vessels which pass up from the foot to the vertical group of superficial inguinal nodes. This is an important part of the course of the **great saphenous vein** (p. 147) for here it has most of its deep connexions. Along the medial side of the calf behind the medial border of the tibia a number of perforating (anastomotic) veins connect the great saphenous with deep veins of the calf (Fig. 3.2). There is usually one just below, one just above, and one about 10 cm above, the medial malleolus and another near the middle of the leg, but there may be others, including one just below knee level. Higher up there is also a constant and rather long perforator in the lower thigh joining the great saphenous or one of its tributaries to the femoral vein in the adductor canal. The lower perforators are frequently joined together by a superficial longitudinal trunk, the **posterior arch vein**, which usually joins the great saphenous some way below the knee. When traced deeply through the deep fascia, some of the perforating veins in the leg are seen to join the venae comitantes of the posterior tibial artery, while others join the venous plexus deep to soleus. The valves in the perforating veins are directed inwards and are found where the veins pierce the deep fascia and also where they join the deep veins. Much of the saphenous blood passes from superficial to deep through the perforators, to be pumped upwards in the deep veins by the contractions of soleus and other calf muscles. If the valves in the perforators become incompetent, pressure in the saphenous system increases and the veins

become varicose. However, some of the smaller perforators do not have valves, and it appears normal for bloodflow in them to occur in either direction.

The upper end of the subcutaneous surface of the shaft of the tibia receives the tendons of three **muscles** that converge from the three constituent parts of the hip bone (Fig. 3.54). They are sartorius (supplied by the femoral, the nerve of the ilium), gracilis (supplied by the obturator, the nerve of the pubis) and semitendinosus (supplied by the sciatic, or ischiadic, the nerve of the ischium) in that order from before backwards. The three tendons are separated by a bursa which lies deep to the flattened sartorius tendon (Fig. 3.35). When distended by fluid the extensions of the bursa alongside the tendons give a fancied resemblance to a goose's foot. The bursa was thus named *bursa anserina*.

It is noteworthy that all three muscles, running up from the tibia, are as widely separated above as the bony pelvis will allow (Fig. 3.35). Are they three 'guy ropes', helping to stabilize the bony pelvis? If so, it would explain the existence of sartorius and gracilis. Of sartorius we say it is a weak flexor and rotator of both

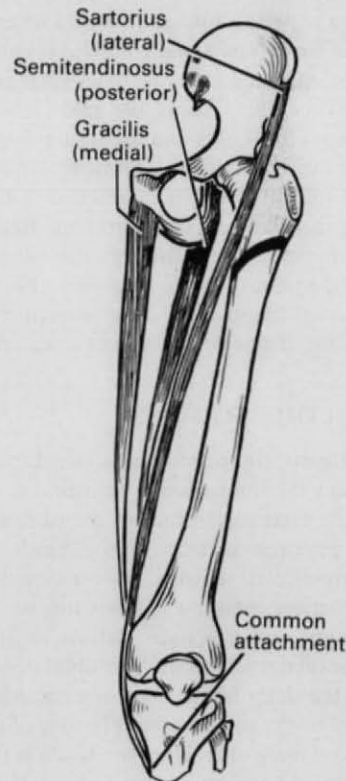


Fig. 3.35 Three muscular 'guy ropes' from the tibia to the pelvis.

hip and knee — but why have such a weak muscle when each joint already possesses its own powerful flexors and rotators? And gracilis is counted as a weak adductor of the thigh; why have a weak adductor when three other powerful adductors are already there? If indeed guy ropes were to be installed between the shin bone on which we stand and the mobile pelvis high above, they could not be situated to better advantage than are these three muscles.

The **patellar ligament** is received into a *smooth* area that lies obliquely on the tibial tuberosity. This insertion is situated entirely upon the epiphysis of the upper end of the tibia (Fig. 3.57). The patellar retinacula, fibrous expansions from the tendon of the quadriceps femoris, are inserted into the edges of the patella and patellar ligament and into the inferior borders of the tibial condyles. The prepatellar bursa (swollen in housemaid's knee) lies in front of the patella, but there are two infrapatellar bursae. The superficial infrapatellar bursa (swollen in clergyman's knee) lies in front of the patellar ligament, the deep infrapatellar bursa lies between the ligament and the upper part of the head of the tibia.

The **deep fascia** of the leg covers only muscles, being attached to periosteum at all places where bone is subcutaneous. Below the tibial condyles it encloses the muscles of the leg, being attached to anterior and posterior borders of the tibia. Above the ankle it is attached also to the lateral malleolus and the triangular subcutaneous area of the fibula. Two intermuscular septa pass from its deep surface to become attached to the fibula. They enclose the peroneal compartment. Between the anterior intermuscular septum and the tibia lies the extensor compartment, while between the posterior intermuscular septum and the tibia posteriorly lies the much more bulky flexor compartment or calf of the leg.

EXTENSOR COMPARTMENT

The compartment comprises the space between the deep fascia and the interosseous membrane, bounded medially by the extensor surface of the tibia and laterally by the extensor surface of the fibula and the anterior intermuscular septum. Its contained muscles are tibialis anterior, extensor hallucis longus, extensor digitorum longus and peroneus tertius, together with the deep peroneal nerve and anterior tibial vessels. In its lower extent the deep fascia does not encircle the leg but is attached to the subcutaneous border of the fibula above the lateral malleolus. Here the fascia is thickened to form the **superior extensor retinaculum** (Fig. 3.36), which is characterized by the fact that the tibialis anterior tendon perforates it, splitting off a

lamina, so that there is a double attachment to the tibia. As it lies in the channel the tendon of tibialis anterior possesses a synovial sheath which continues down to its insertion. The other extensor tendons pass deep to the superior extensor retinaculum and at this level possess no synovial sheath. The muscle bellies lie lateral to the tibia but their tendons pass across its lower end beneath the superior retinaculum.

Tibialis anterior

This muscle has a spindle-shaped belly that moulds the anterior subcutaneous border of the tibia into a reciprocal concavity. It arises from the upper two-thirds of the extensor surface of the tibia, from the interosseous membrane and, especially strongly, from the upper part of the deep fascia overlying it. It is pierced by the anterior tibial recurrent artery. The multipennate fibres converge conically downwards into a central tendon that pierces the superior extensor retinaculum, from which level the tendon is invested with a continuous synovial sheath. The pressure of the tendon rounds off the anterior border of the lower end of the tibia. Tendon and sheath are slung by the inferior extensor retinaculum (Fig. 3.36) and the tendon is inserted into a *smooth* facet at the anteroinferior angle of the medial cuneiform and into the adjacent part of the first metatarsal bone. A small bursa separates the tendon from the upper part of the facet.

Note that the tibialis anterior and peroneus longus are symmetrical in their insertions into opposite sides of the adjoining medial cuneiform and first metatarsal base, but tibialis anterior is inserted mainly into the cuneiform while peroneus longus tendon is inserted mainly into the metatarsal.

Nerve supply. By the deep peroneal and recurrent genicular nerves (L4).

Action. Combined dorsiflexion of the ankle joint and inversion of the foot (p. 207).

Test. The foot is dorsiflexed against resistance; the tendon can be seen and felt.

Extensor hallucis longus

This muscle arises from the middle two-fourths of the fibula and the adjacent interosseous membrane. (Flexor hallucis longus, too, arises from the fibula.) The muscle lies deep at its origin, but emerges between tibialis anterior and extensor digitorum longus in the lower part of the leg. It passes beneath the superior extensor retinaculum, and is slung by the inferior extensor retinaculum, where it receives a separate synovial sheath. It passes along the medial side of the dorsum of

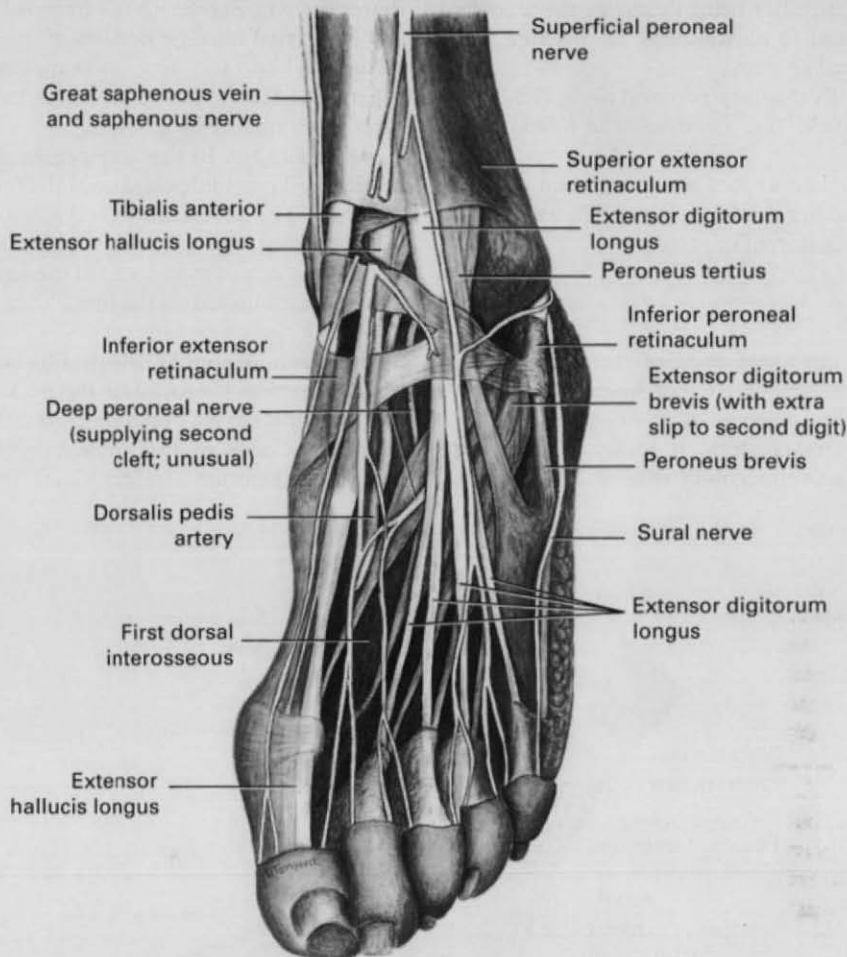


Fig. 3.36 Left lower leg and dorsum of the foot.

the foot and is inserted into the base of the terminal phalanx of the great toe.

Nerve supply. By the deep peroneal nerve (L5, S1).

Action. To dorsiflex (anatomically this is to extend) the great toe. Secondly it is a dorsiflexor of the ankle. Note that dorsiflexion of the great toe 'winds up' the plantar aponeurosis around the 'pulley' of the head of the metatarsal bone and so increases the concavity of the medial longitudinal arch of the foot (p. 209).

Test. The big toe is dorsiflexed against resistance; the tendon can be seen and felt.

Extensor digitorum longus

This arises from the upper three-quarters of the extensor surface of the fibula and from a small area of

the tibia across the superior tibiofibular joint. Much of the muscle gains origin from the anterior intermuscular septum and, to a less extent, from the deep fascia overlying it. It forms its four tendons over the lower part of the tibia, beneath the superior extensor retinaculum (Fig. 3.36). They are slung together by the inferior extensor retinaculum, and are here enclosed with the tendon of peroneus tertius in a common synovial sheath. The four tendons diverge slightly, superficial to extensor digitorum brevis, just beneath the deep fascia on the dorsum of the foot. They are inserted into the lateral four toes. Their mode of insertion is precisely the same as that of the extensor digitorum tendons in the hand. The tendon divides into three slips over the proximal phalanx, the central slip being inserted into the base of the middle phalanx. The

two side slips reunite after being joined by the tendons of the interossei and lumbricals and are inserted into the base of the distal phalanx.

Nerve supply. By the deep peroneal nerve (L5, S1).

Action. To extend (i.e. dorsiflex) the lateral four toes.

Test. The four lateral toes are dorsiflexed against resistance; the tendons can be seen and felt, with some assistance in dorsiflexion of the ankle.

Peronius tertius

This arises from the lower third of the fibula below extensor digitorum longus. It is a unipennate muscle whose tendon forms anteriorly, in contact with the superior extensor retinaculum. It passes through the stem of the inferior retinaculum (Fig. 3.36) where it

shares the synovial sheath of extensor digitorum longus and is inserted into the dorsum of the base of the fifth metatarsal bone and, by a falciform extension, into the superior surface of that bone as far forwards, in many cases, as its neck (Fig. 3.37).

Nerve supply. By the deep peroneal nerve (L5, S1).

Action. To dorsiflex and evert the foot. In spite of its small size it possesses fairly good mechanical advantage in dorsiflexion, since its tendon passes some distance in front of the axis of movement of the ankle and its insertion is so far forward on the foot.

The **deep peroneal (deep fibular) nerve** arises within peroneus longus, over the neck of the fibula, at the bifurcation of the common peroneal nerve. It spirals around the neck of the fibula deep to the fibres of extensor digitorum longus, and so reaches the

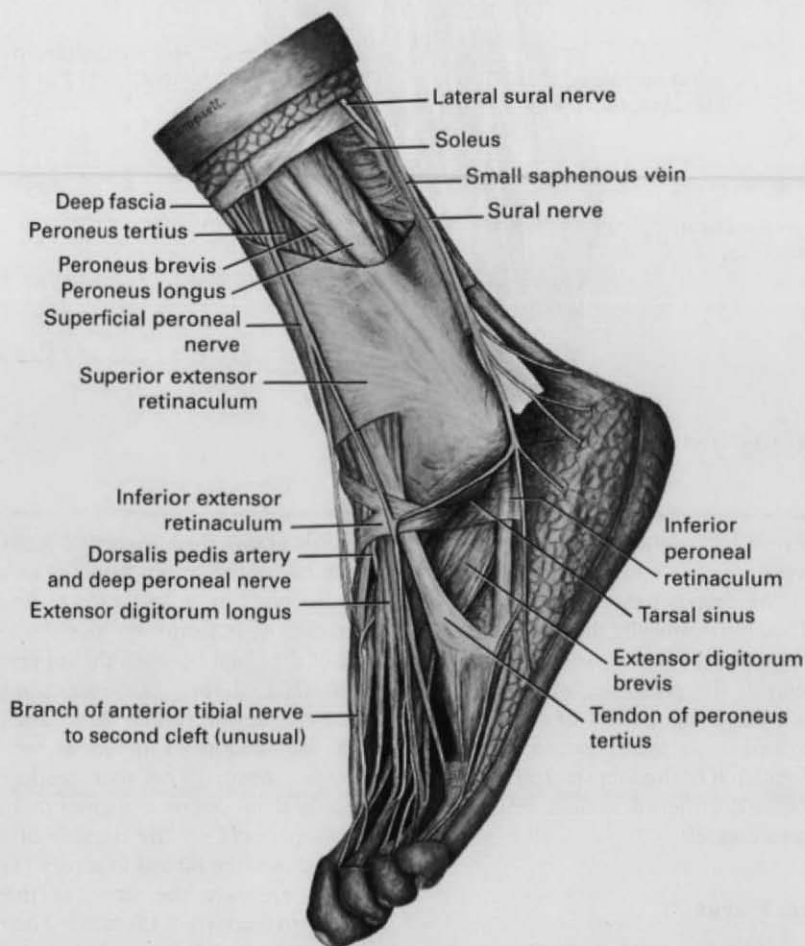


Fig. 3.37 Left foot and ankle from the lateral side.

interosseous membrane, on the lateral side of the anterior tibial vessels. With them it lies between extensor digitorum longus and tibialis anterior, the only two muscles in the upper part of the extensor compartment. In the middle of the leg the neurovascular bundle lies on the interosseous membrane between the tibial and fibular muscles, i.e. tibialis anterior and extensor hallucis longus. The latter muscle crosses the bundle, so that over the lower end of the tibia the tendons of two muscles lie on each side of the bundle (tibialis anterior and extensor hallucis longus medially, and extensor digitorum longus and peroneus tertius laterally). At this level the deep peroneal nerve has regained its position lateral to the vessels.

The deep peroneal nerve supplies the four muscles of the extensor compartment of the leg, and is sensory to the periosteum of the extensor surfaces of tibia and fibula. For its further course in the foot, see page 191.

The **anterior tibial artery**, formed at the bifurcation of the popliteal artery in the calf, passes forwards above the upper border of the interosseous membrane to reach the extensor compartment. In doing so it lies nearer the fibula than the tibia, with a companion vein on each side. The fibular companion vein may leave a notch in the fibula, visible in a radiograph. The artery with its companion veins runs vertically downwards on the interosseous membrane and crosses the lower end of the tibia at the front of the ankle joint, midway between the malleoli, where it changes its name to the dorsalis pedis artery. It gives off a recurrent branch, which pierces tibialis anterior, to the arterial anastomosis around the upper end of the tibia, supplies the muscles of the extensor compartment and gives malleolar branches to both malleolar regions.

Tibialis anterior lies to its medial side of the artery throughout. Extensor digitorum longus and peroneus tertius lie to its lateral side throughout. Extensor hallucis longus crosses it from fibular to tibial sides. The deep peroneal nerve reaches it from the lateral side, runs in front of it in the crowded space of the middle of the leg and returns to its lateral side below. The **anterior tibial veins** run, one on each side of the artery, in close contact with it and anastomose by cross channels at frequent intervals.

TIBIOFIBULAR JOINTS

The fibula articulates with the femur in the embryo, but differential growth of tibia and fibula results in the latter sinking below the level of the plateau of the tibia and making a separate tibiofibular articulation. This is a synovial joint, with capsule and synovial membrane. The lower ends of the two bones are

strongly bound together by ligamentous fibres to form a fibrous joint and the two bones are further held together by an interosseous membrane which connects their interosseous borders. The nature of the tibiofibular articulations varies widely from animal to animal, and suppression of upper or lower end of the fibula is quite common.

The presence of a synovial joint at the upper ends of the two bones in man indicates movement, but this movement is entirely passive and depends upon the variable shape of the talus. The fibular malleolus maintains intimate contact with the lateral surface of the talus in all positions of the ankle joint. The lateral surface of the talus is usually convex in an anteroposterior direction, so that dorsiflexion and plantar flexion at the ankle joint produce rotation of the fibula around its own axis. In such cases the superior tibiofibular joint surfaces are more nearly horizontal, to allow rotation to occur. If the lateral surface of the talus is plane, the superior tibial and fibular facets are more nearly vertical.

The **superior tibiofibular joint**, with these variations in the direction of its surface, is surrounded by a capsule (Fig. 3.30) whose fibres are thickened anteriorly and posteriorly and from the tibia slope downwards to the fibula. The joint cavity may communicate posteriorly with the bursa under the popliteus tendon and thence with the knee joint.

The **interosseous membrane** consists of strong fibres that slope steeply from the tibia down to the fibula. They do more than bind the bones together, for they resist downward movement of the fibula when the powerful fibular muscles pull on it (flexor hallucis longus, the peronei, extensor hallucis and digitorum longus). The only muscle exerting an upward pull on the fibula is the biceps femoris.

The **inferior tibiofibular joint** is a fibrous joint, the two bones being strongly bound together by the interosseous tibiofibular ligament whose fibres occupy the triangular area on each bone at the lower end of the interosseous border (Fig. 3.61).

PART 7 DORSUM OF THE FOOT

The skin of the dorsum of the foot is supplied by the superficial peroneal nerve, assisted slightly by the deep peroneal, saphenous, and sural nerves (Fig. 3.52). The large veins form a **dorsal venous arch** which receives most of its blood by marginal and interosseous tribu-

aries from the sole of the foot. The dorsal venous arch, lying over the heads of the metatarsals, drains from its medial and lateral ends into the great and small saphenous veins respectively.

The **superficial peroneal (superficial fibular) nerve** surfaces at the middle of the leg (Fig. 3.36). It passes downwards over the peronei and divides above the ankle into medial and lateral branches which supply the skin of the dorsum of the foot. The medial branch further divides to supply the medial side of the dorsum of the great toe and the sides of the *second* cleft. The lateral branch divides to supply the third and fourth clefts. The nerve and its divisions are visible in a thin leg when stretched by plantarflexion of the foot. The lateral side of the foot and lateral side of the little toe are supplied by the sural nerve, while the *first* cleft is supplied by the deep peroneal nerve. The terminal phalanges and toenails are supplied by the medial and lateral plantar nerves. The medial side of the foot as far forward as the bunion area (metatarsophalangeal joint) is supplied by the termination of the saphenous nerve.

The subcutaneous layer of the dorsum of the foot, as of the hand, contains but little fat in most people, and the veins are consequently easily seen when distended.

The **deep fascia** on the dorsum of the foot binds down the underlying tendons, and a Y-shaped thickening beneath it (the inferior extensor retinaculum) prevents bowstringing of the extensor tendons as they pass across the front of the ankle joint, acting like an ankle strap.

The **inferior extensor retinaculum** arises by a stem from the anterior part of the upper surface of the calcaneus, on the lateral border of the dorsum of the foot (Fig. 3.36). From the stem two limbs diverge. The upper limb is attached to the medial malleolus, the lower limb arches across the tendons on the dorsum and blends with the plantar aponeurosis under the medial longitudinal arch of the foot. The tendons are usually said to pierce the extensor retinaculum, but this is not strictly true. Most of the inferior retinacular fibres sling around the tendons and return to be attached to the calcaneus, and only the superficial fibres pass across to the insertions mentioned at the medial malleolus and plantar aponeurosis (Fig. 3.40). All the extensor tendons are enclosed in synovial sheaths where they are slung in the inferior extensor retinaculum.

Extensor digitorum brevis

This is a muscle whose fleshy belly can be seen in most feet and felt in all. It arises from the upper surface of the calcaneus and from the deep surface of the stem of the Y-shaped inferior extensor retinaculum. It passes

obliquely across the dorsum of the foot and gives off four tendons to the *medial* four toes. The tendon to the great toe is different from the others and is deservedly given a special name, **extensor hallucis brevis**. Its belly usually separates early from the main muscle mass and the tendon is inserted separately into the base of the proximal phalanx of the great toe. As in the thumb, so in the great toe there is no dorsal extensor expansion. The remaining three tendons are inserted into the dorsal extensor expansions of the second, third and fourth toes. All four tendons of the muscle pass deep to the tendons of extensor digitorum longus.

Nerve supply. By the deep peroneal nerve (S1, 2); the branch enters the medial side of the muscle.

Action. To extend the medial four toes. It is particularly of value when the long extensor is out of action, in the fully dorsiflexed ankle, as in the moment just before the take-off from the hind foot in walking, running, and jumping. The toes thus extended lengthen the grip of the foot on the ground, and this provides a faster propulsive take-off.

Test. The toes are dorsiflexed and the muscle belly towards the lateral side of the dorsum (not the tendons) is observed and palpated.

The anterior tibial artery, lying over the lower end of the tibia midway between the malleoli, extends forwards as the **dorsalis pedis artery** (Fig. 3.36). This runs to the base of the first intermetatarsal space and passes down into the sole, where it joins the lateral plantar artery to complete the plantar arch. It lies between the tendon of extensor hallucis longus medially and the digital branch of the deep peroneal nerve laterally, and it is crossed by the tendon of extensor hallucis brevis. Its *pulsation* can be felt lateral to the extensor hallucis longus tendon on a line from the midpoint between the two malleoli towards the first toe cleft. Beware of a twitching extensor tendon that can be mistaken for this pulse! Occasionally the vessel is replaced by an enlarged perforating peroneal artery in front of the lateral malleolus. It has three named branches. The **lateral tarsal artery** runs laterally beneath extensor digitorum brevis, to supply that muscle and the underlying tarsal bones. The **arcuate artery** runs laterally beneath the tendons of extensor digitorum brevis over the bases of the metatarsal bones. It gives off dorsal metatarsal arteries to supply the lateral three clefts. Each metatarsal artery gives off a perforating branch at the posterior and anterior end of its intermetatarsal space to communicate with the plantar arch and its digital branches. It is the accompanying perforating veins that are responsible for bringing much of the blood from the sole of the foot

through the intermetatarsal spaces to the dorsal venous arch. The *first dorsal metatarsal artery*, a direct continuation of the *dorsalis pedis*, supplies the first cleft and the medial side of the dorsum of the great toe.

The **deep peroneal (deep fibular) nerve** crosses the tibia lateral to the artery, midway between the malleoli. It passes forward, deep to the tendons, on the lateral side of the *dorsalis pedis* artery, to pierce the deep fascia and supply the first cleft. It gives off a branch which curves laterally beneath the muscle belly of *extensor digitorum brevis* and supplies this muscle and the underlying periosteum and joint capsules. It may also give a branch as an additional supply to the first dorsal interosseous muscle.

PART 8 LATERAL COMPARTMENT OF THE LEG

This muscular compartment lies between the peroneal surface of the fibula and deep fascia of the leg and is bounded in front and behind by the anterior and posterior intermuscular septa. It contains the *peroneus longus* and *brevis* muscles and the superficial peroneal nerve. Its blood supply is derived from branches of the peroneal artery which pierce *flexor hallucis longus* and the posterior intermuscular septum. Its veins drain, for the most part, into the small saphenous vein.

Peroneus longus and peroneus brevis

Peroneus longus arises from the upper two-thirds of the peroneal surface of the fibula, from the head of that bone and, across the superior tibiofibular joint, from a small area of the lateral tibial condyle. Its fibres take origin also from the intermuscular septa. **Peroneus brevis** arises from the lower two-thirds of the fibula; in the middle third of the bone its origin lies in front of that of *peroneus longus* and the two muscles and their tendons maintain this relationship.

The broad tendon of *peroneus brevis* lies behind (and grooves) the lateral malleolus. The narrower tendon of *peroneus longus* lies on that of *brevis* and does not come into contact with the malleolus (Fig. 3.39). The two tendons pass forwards to the peroneal trochlea on the lateral surface of the calcaneus, which separates them. The tendon of *brevis* passes above the peroneal trochlea to be inserted into the tip of the tubercle (styloid process) at the base of the fifth metatarsal bone. The tendon of *peroneus longus* passes below the peroneal trochlea and enters the sole

of the foot, lying against the posterior ridge of the groove on the cuboid bone. Here the tendon possesses a sesamoid fibrocartilage which often ossifies. The tendon crosses the sole obliquely to be inserted into the base of the first metatarsal and the adjoining part of the medial cuneiform (Fig. 3.44).

The tendons are bound down at the lateral malleolus by the **superior peroneal retinaculum**, a band of deep fascia that extends from the tip of the malleolus to the calcaneus, and at the peroneal trochlea by the **inferior peroneal retinaculum** (Fig. 3.37). This is a band of fascia attached to the peroneal trochlea and to the calcaneus above and below the peroneal tendons. Its upper part is continuous with the stem of the Y-shaped inferior extensor retinaculum. The two tendons are enclosed in a common *synovial sheath* from above the lateral malleolus to the peroneal trochlea, where the sheath divides to accompany each tendon separately to its insertion.

Nerve supplies. Both muscles are supplied by the superficial peroneal nerve (L5, S1).

Action. Both muscles evert, and weakly plantarflex, the foot; they are the plantarflexors when the tibial nerve is paralysed. In addition, *peroneus longus* is a factor in maintaining the lateral longitudinal and transverse arches of the foot (p. 211).

Test. The foot is everted and the tendons can be seen and felt below the lateral malleolus.

The **superficial peroneal (superficial fibular) nerve** begins in the substance of *peroneus longus* at the division of the common peroneal nerve. It passes downwards in the muscle and emerges at its anterior border behind the anterior intermuscular septum. It supplies both peronei and pierces the deep fascia halfway down the leg and soon divides into medial and lateral branches. In thin individuals these can be seen or felt as ridges under the skin if they are put on the stretch by full plantar flexion of the foot (Fig. 3.37). The distribution on the dorsum of the foot has been described on page 190.

PART 9 POSTERIOR COMPARTMENT OF THE LEG

This is commonly called the **calf**. The skin of the calf is supplied by the termination of the posterior femoral cutaneous nerve halfway to the ankle. Below this level the sural and peroneal communicating nerves, from

tibial and common peroneal nerves, supply the back and lateral side of the calf, and the saphenous nerve supplies the medial side (Fig. 3.53).

The **small (short) saphenous vein**, draining the lateral side of the dorsal venous arch and the lateral margin of the foot lies with the sural nerve behind the lateral malleolus. It passes upwards in the subcutaneous fat along the midline of the calf and pierces the deep fascia anywhere from midcalf to the roof of the popliteal fossa, where it enters the popliteal vein; it may thus run for some distance beneath the deep fascia. It communicates by several channels with the great saphenous vein (p. 185).

The deep fascia is a continuation downwards from the popliteal fascia and is attached to the posterior border of the tibia. It surrounds the calf and the peroneal and extensor compartments to become attached to the anterior border of the tibia. Where the lower end of the fibula becomes subcutaneous the deep fascia is attached to the periosteum. The posterior intermuscular septum divides the calf from the peroneal compartment.

The deep fascia is thickened above the heel, where it is attached to the tibia and fibula across the tendo calcaneus (Achilles' tendon) forming a 'pulley' for the tendon and separated from it by a bursa. A further thickening of fascia bridges the deep flexor tendons and neurovascular bundle; it stretches from the medial

malleolus to the back of the calcaneus, and forms the *flexor retinaculum*.

The muscles of the calf, the posterior compartment of the leg, fall into superficial and deep groups. The superficial muscles consist of gastrocnemius, plantaris and soleus which all converge on a thick tendon at the back of the heel, the tendo calcaneus or Achilles' tendon. They are the main plantarflexors of the ankle joint. The deep group includes popliteus (which has been more conveniently described with the popliteal fossa, p. 173), and three muscles — flexor digitorum longus, flexor hallucis longus and tibialis posterior — whose tendons pass under the flexor retinaculum into the sole of the foot. The nerve of the posterior compartment is the tibial part of the sciatic, and the arteries are the posterior tibial (from the popliteal) and its peroneal branch. Refer to Figure 3.38 when the above structures are being studied.

SUPERFICIAL MUSCLES OF THE CALF

Gastrocnemius and plantaris

Examine the lower end of a femur. The epiphyseal junction passes transversely through the adductor tubercle. The lateral head of gastrocnemius arises from

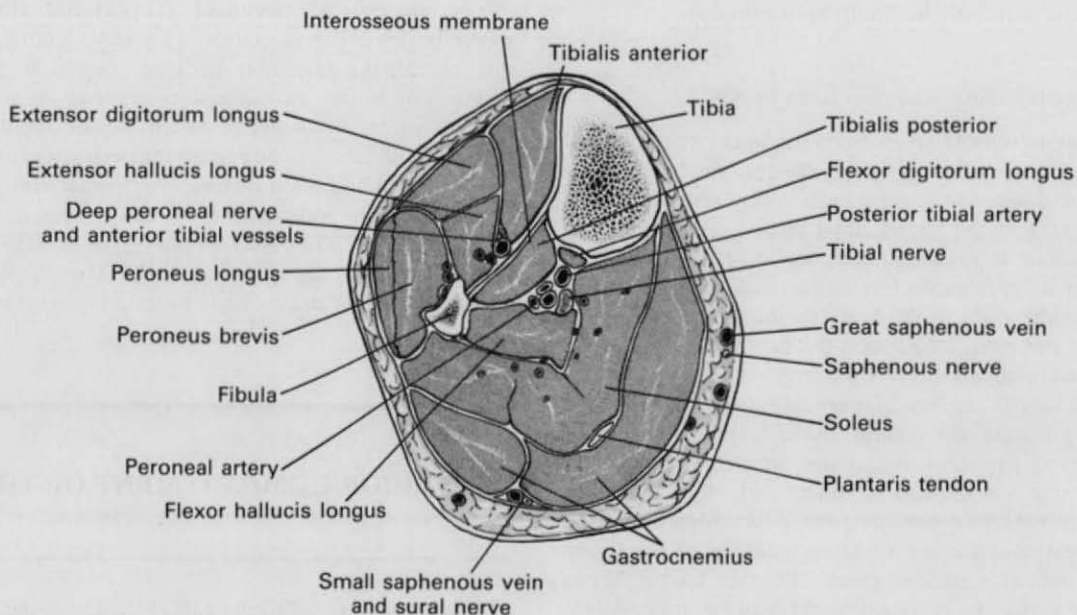


Fig. 3.38 Cross-section of the middle of the right upper leg, looking towards the knee. Tibialis posterior is the deepest calf muscle, immediately behind the interosseous membrane. Note the many veins associated with soleus — a potential site of dangerous deep venous thrombosis.

the epiphysis, the medial head from both epiphysis and shaft; plantaris arises from the shaft. The **lateral head** of **gastrocnemius** arises on the *lateral surface* of the lateral condyle, by a tendon that leaves a smooth pit above that of popliteus; the pits are separated by the epicondyle (Fig. 3.33A). A few fleshy fibres arise from the condyle above the pit, towards the lower end of the lateral supracondylar line. The **medial head** of **gastrocnemius** arises by a tendon from a smooth shallow pit on the medial condyle at the lower end of the medial supracondylar line and by muscular fibres from an area of roughened bone on the popliteal surface of the shaft of the femur (Figs 3.56 and 3.26). In the fetus the medial head, like the lateral, arises wholly from the epiphysis; the upward extension of this origin to encroach on the popliteal surface of the shaft of the femur is a postnatal event.

The two heads converge to lie side by side, where the broad bellies of the muscle have a dense aponeurosis beneath them, bearing on the soleus muscle. The medial head is longer at each end; it extends below the lateral head, as inspection of the living calf will show. The flat aponeurosis blends with that of soleus at the lower border of the lateral head. In the midline it blends with soleus aponeurosis by a criss-cross exchange of fibres. The medial half of the aponeurosis is separate from soleus down to the heel, and the slender tendon of plantaris lies between. A bursa lies between the medial head and the capsule over the medial condyle of the femur. It communicates with the knee joint and it may communicate also with the semimembranosus bursa (Fig. 3.32).

The aponeurosis forms, with that of soleus, the *tendo calcaneus* (Achilles' tendon), which is inserted into a smooth transverse area on the middle third of the posterior surface of the calcaneus. A bursa lies between it and the upper part of the calcaneus. A second bursa lies between it and the thickened deep fascia 2 inches above its insertion; inflammation here is frequently misnamed 'tenosynovitis'. There is no synovial sheath around the *tendo calcaneus* (Fig. 3.37).

Plantaris is a vestigial muscle showing the short belly and long tendon said to indicate phylogenetic degeneration. It arises from the shaft of the femur at the lower part of the lateral supracondylar line, lying edge to edge with the lateral head of **gastrocnemius** (Fig. 3.22). Its slender tendon runs deep to the medial head of **gastrocnemius** and down the midline of the calf, between the aponeuroses of **gastrocnemius** and **soleus** (Fig. 3.40), to the calcaneus at the medial side of the *tendo calcaneus*. The tendon is flat as it lies sandwiched between the two aponeuroses, but it can be

unravelling and proves to be a wide ribbon twisted spirally upon itself.

Soleus

There is great morphological resemblance between soleus in the leg and *flexor digitorum superficialis* in the forearm. Structurally they are different. *Flexor digitorum superficialis* has parallel fibres for range of movement of the fingers, soleus is multipennate for power in propulsion. The *flexor digitorum brevis* muscle in the sole of the foot can be regarded as the divorced distal part of soleus, cut off from it by the posterior projection of the calcaneus.

The muscle arises from the fibula and tibia, mostly the tibia. The upper fourth of the fibula, including the head of the bone, gives some origin to the muscle, whence a fibrous arch (which bridges over the popliteal vessels and tibial nerve) carries it in continuity to the soleal line of the tibia and the fascia upon popliteus above this line, and so along the posterior border of the middle third of the tibia, that is, a hand's breadth below the lower end of the soleal line (Fig. 3.39A). The muscle has a curious and characteristic structure: it is flat, and there is a dense aponeurosis upon either surface. Between the two aponeurotic lamellae lies the great bulk of the soleus, made up of muscle fibres that slope downwards from the anterior to the posterior lamella; these fleshy fibres are visible at the medial and lateral borders of the muscle. The posterior (superficial) lamella is continued at its lower end into the *tendo calcaneus*, and the muscle fibres of soleus are received into its deep surface down to within a short distance of the calcaneus. The *tendo calcaneus* is received into a smooth transverse area across the middle third of the posterior surface of the calcaneus (Fig. 3.62).

If the soleus is detached from its fibular origin and turned aside the anterior surface is brought into view. Here a slender bipennate muscle belly is attached to the centre of the aponeurosis. This belly lies on the neurovascular bundle, in the groove between *flexor digitorum longus* and *flexor hallucis longus*. Branches from the posterior tibial vessels perforate the aponeurosis.

Perforating veins from the great saphenous vein enter the substance of soleus. The muscle contains a rich plexus of small veins, and these are pumped empty by contraction of the muscle, thus aiding venous return. *Stagnation in these veins predisposes to deep venous thrombosis and the danger of pulmonary embolism* (Fig. 3.38). The 'soleal pump' is aided by the 'sole pump' (p. 203).

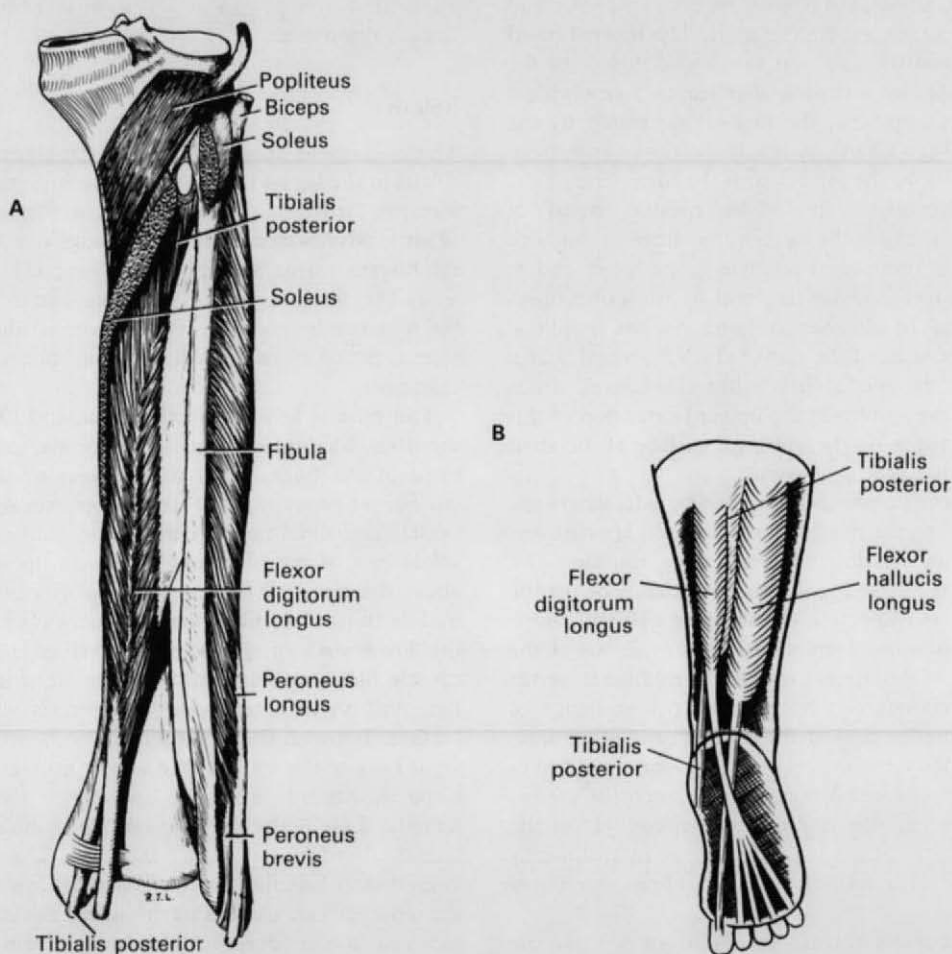


Fig. 3.39 Deep muscles of the right calf. **A** The origin of flexor digitorum longus (with flexor hallucis longus removed). **B** Showing flexor digitorum longus crossing superficial to tibialis posterior in the lower calf and to flexor hallucis longus in the sole. Tibialis posterior and flexor hallucis longus are parallel.

Nerve supply. All three muscles are supplied by the tibial nerve (S1, 2). Each head of gastrocnemius receives a branch from the nerve in the popliteal fossa, where the small branch to plantaris also arises. Soleus receives two branches, one from above the muscle in the popliteal fossa and one on its deep surface in the calf. In cases of intractable intermittent claudication both branches must be cut if soleus is to be completely denervated.

Actions. Soleus and gastrocnemius act together on the tendo calcaneus; the action of the weak vestigial plantaris is negligible. The powerful multipennate soleus is an antigravity muscle. In standing it contracts alternately with the extensor muscles of the leg to

maintain balance. It is a very strong but relatively slow plantar flexor of the ankle joint, a necessary mechanical result of the obliquity of its multipennate fibres. The gastrocnemius bellies are not multipennate; their fibres all lie roughly vertical in the long axis of the leg. They provide the necessary 'whip-like' contraction that aids rapid propulsion. This action is greatly increased if the flexed knee is simultaneously extended, for the origin of the contracting muscle is thereby pulled upwards and the tendo calcaneus with it. In propulsion the powerful, multipennate soleus overcomes the inertia of the body weight (bottom gear), and when movement is under way the quicker-acting gastrocnemius greatly increases the speed of movement (top gear). One strolls along

quietly mainly with soleus; one wins the long jump mainly with gastrocnemius (see p. 194). Gastrocnemius can also assist in knee flexion, but if this is the required movement the muscle's maximum force cannot then be applied to plantarflexion, and vice versa.

Test. The foot is plantarflexed against resistance; the tendo calcaneus and muscles above it can be seen and palpated.

DEEP MUSCLES

The deep muscles of the calf consist of flexor digitorum longus, flexor hallucis longus and tibialis posterior. Their three tendons pass under the flexor retinaculum into the sole of the foot. Those of tibialis posterior and flexor hallucis longus are parallel throughout their course, the tibialis medial to the hallucis. The tendon of flexor digitorum longus takes an oblique course *superficial to both*. In the calf it lies medially, crosses tibialis posterior to lie under the flexor retinaculum between the two, and in the sole it crosses flexor hallucis longus to pass to the lateral four toes (Fig. 3.39B).

Flexor digitorum longus

This muscle is often described inaccurately. It is a bipennate muscle that arises from *both bones* of the leg. Its tibial origin is by flesh from the posterior surface of the bone below the soleal line, but, by virtue of the intermuscular septa in this region, it can also be shown to arise *from the fibula by a broad aponeurosis* whose oblique fibres are replaced by flesh to form the lateral half of the bipennate muscle (Fig. 3.39A). The tendon forms centrally in the bipennate mass and slopes downwards across the tendon of tibialis posterior in the lower part of the leg. Passing beneath the flexor retinaculum it enters the sole of the foot, and crosses the tendon of flexor hallucis longus. At this point it divides into four tendons, the medial two of which *receive a strong slip from the tendon of flexor hallucis longus*. The four tendons at their commencement receive the insertion of the flexor accessorius muscle. More distally each gives origin to a lumbrical muscle. The tendons pass into the fibrous flexor sheaths of the lateral four toes, perforate the tendons of flexor digitorum brevis, and are inserted into the bases of the distal phalanges (for lumbricals, see p. 199).

Nerve supply. By the tibial nerve (S1, 2).

Action. Its principal action is to plantarflex the lateral four toes and, secondarily, to plantarflex the ankle joint. Its tonus is, with that of the other deep calf muscles, indispensable in maintaining the longitudinal arch of the foot.

Flexor hallucis longus

This is the bulkiest and most powerful of the three deep muscles of the calf and its importance is usually not given due credit. It is a multipennate muscle whose fibres arise from the flexor surface of the fibula *and from the adjoining aponeurosis of the flexor digitorum longus*. Below this the muscle arises in continuity from the whole flexor surface of the fibula and the lower part of the interosseous membrane (Fig. 3.60).

The fibres spiral down to be inserted into a central tendon which escapes from the muscle just at the lower end of the tibia. 'Beef to the heel' describes the flexor hallucis longus. The tendon grooves the posterior process of the talus and the under surface of the sustentaculum tali (Figs 3.50 and 3.64), from which it passes directly forwards like a bowstring beneath the arched medial border of the foot to be inserted into the base of the distal phalanx of the great toe.

It is crossed in the sole by the tendons of flexor digitorum longus (Fig. 3.39B) and gives a strong slip to the medial two of these (those for the second and third toes). The peroneal artery runs down deep to it on the fibular aponeurosis of flexor digitorum longus. The artery is covered by a fibrous roof on the deep surface of flexor hallucis longus.

Nerve supply. By the tibial nerve (S1, 2).

Action. Its principal action is to flex the great toe, and it is significant that this is the 'take-off' point, the last part to leave the ground in propulsion. It plantarflexes the ankle joint simultaneously. In addition, the pull of this powerful muscle is the most important single factor in maintaining the medial longitudinal arch of the foot (p. 210).

Tests. The terminal phalanges of the great toe (for flexor hallucis longus) and of other toes (for flexor digitorum longus) are flexed against resistance.

Tibialis posterior

This muscle arises from the interosseous membrane and the adjoining surface of both bones of the leg below the origin of soleus and from the fibular aponeurosis of flexor digitorum longus. It is pierced by the nutrient artery of the tibia. It is a unipennate muscle, the tendon emerging from its medial side and lying in close contact with the edge of the tibia. The tendon grooves the back of the medial malleolus (Fig. 3.39A); the groove in life is deepened by fibrocartilage which is lost from the dried bone. It passes forward above the medial side of the sustentaculum tali, and is inserted into the tuberosity of the navicular. The glib statement that it is inserted into 'every bone of the tarsus except the talus' is misleading

(see p. 202). Most of the 'expansions' that pass from its insertion on the navicular to other tarsal bones are ligaments in their own right, and not extensions of the tendon. Its blood supply is derived from the *peroneal artery* by branches that pierce the aponeurosis of flexor digitorum longus. Very few branches of the posterior tibial artery reach the muscle, which is pierced by the nutrient artery to the tibia.

Nerve supply. By the tibial nerve (L4, see p. 26).

Action. To invert and adduct the forefoot and, since it passes behind the medial malleolus, to plantarflex the ankle joint.

Test. With the foot in slight plantarflexion, it is inverted against resistance; the tendon can be seen and felt behind the medial malleolus.

The **posterior tibial artery** arises at the lower border of the popliteus, where the popliteal artery divides into anterior and posterior tibial branches. It passes under the fibrous arch in the origin of soleus and runs down on the fibular aponeurosis of flexor digitorum longus, between the muscle bellies of that muscle and flexor hallucis longus. It ends under the flexor retinaculum by dividing into medial and lateral plantar arteries at a slightly higher level than the point of bifurcation of the tibial nerve. It is accompanied throughout its course by a pair of venae comitantes which communicate with each other at frequent intervals around the artery.

The *pulsation* of the artery is felt at the level of the medial malleolus, 2.5 cm in front of the medial border of the tendo calcaneus; it is often the most difficult to feel of the lower limb pulses. It can also be exposed here, e.g. for making an arteriovenous shunt with the great saphenous vein for haemodialysis.

Branches. The *nutrient artery to the tibia* is the largest single nutrient artery in either limb. The vessel pierces the fibular aponeurosis of flexor digitorum longus, passes medially beneath the muscle and then downwards into the bone between the tibial origins of flexor digitorum longus and tibialis posterior.

Various muscular branches supply the overlying soleus, tendo calcaneus and skin.

The *peroneal (fibular) artery* arises an inch below the commencement of the posterior tibial and runs into a tunnel whose fibrous roof gives attachment to muscle fibres of flexor hallucis longus. It gives muscular branches that perforate the fibular aponeurosis of flexor digitorum longus to supply tibialis posterior and others that wind around the fibula to supply peroneus longus and brevis. It gives a nutrient artery to the fibula. It ends by dividing into a perforating branch which pierces the interosseous membrane to enter the

extensor compartment and a lateral calcaneal branch which ramifies behind the lateral malleolus and over the lateral side of the heel.

The **tibial nerve** runs straight down the midline of the calf, deep to soleus, lying on the fibular aponeurosis of flexor digitorum longus. The posterior tibial artery is at first lateral to it, but passes deep to it at the origin of its peroneal branch and continues downwards on its medial side. The nerve ends under the middle of the flexor retinaculum by dividing into the medial and lateral plantar nerves, at a slightly lower level than the bifurcation of the artery (Fig. 3.40). Its *surface marking* is from the middle of the popliteal fossa to behind the medial malleolus.

It is the nerve of the flexor compartment, giving muscular branches to the deep surface of soleus, to flexors digitorum longus and hallucis longus, and tibialis posterior. It gives off several cutaneous twigs, the *medial calcaneal nerves*, to the skin of the heel, including the weight-bearing surface (Fig. 3.40).

PART 10

SOLE OF THE FOOT

The **skin** is supplied posteriorly, over the weight-bearing part of the heel, by the medial calcaneal branches of the tibial nerve. The sole is supplied from the medial and lateral plantar nerves by branches that perforate the plantar aponeurosis along each edge of the strong central portion. Blood vessels accompany all the cutaneous nerves of the sole. The plantar surfaces of the toes are supplied by digital branches of the medial (three and a half toes) and lateral (one and a half toes) plantar nerves. Note that the plantar digital nerves supply skin on the dorsum of each toe proximal to the nail bed. Compare the median and ulnar nerve distributions to the fingers; they are identical.

The **subcutaneous tissue** in the sole, as in the palm, differs from that of the rest of the body in being more fibrous. Fibrous septa divide the tissue into small loculi which are filled with a rather fluid fat under tension, so that the cut tissue bulges. This makes a shock-absorbing pad, especially over the heel. The septa anchor the skin to the underlying plantar aponeurosis, to improve the 'grip' of the sole.

The **plantar aponeurosis** covers the whole length of the sole (Fig. 3.41). It arises posteriorly from the

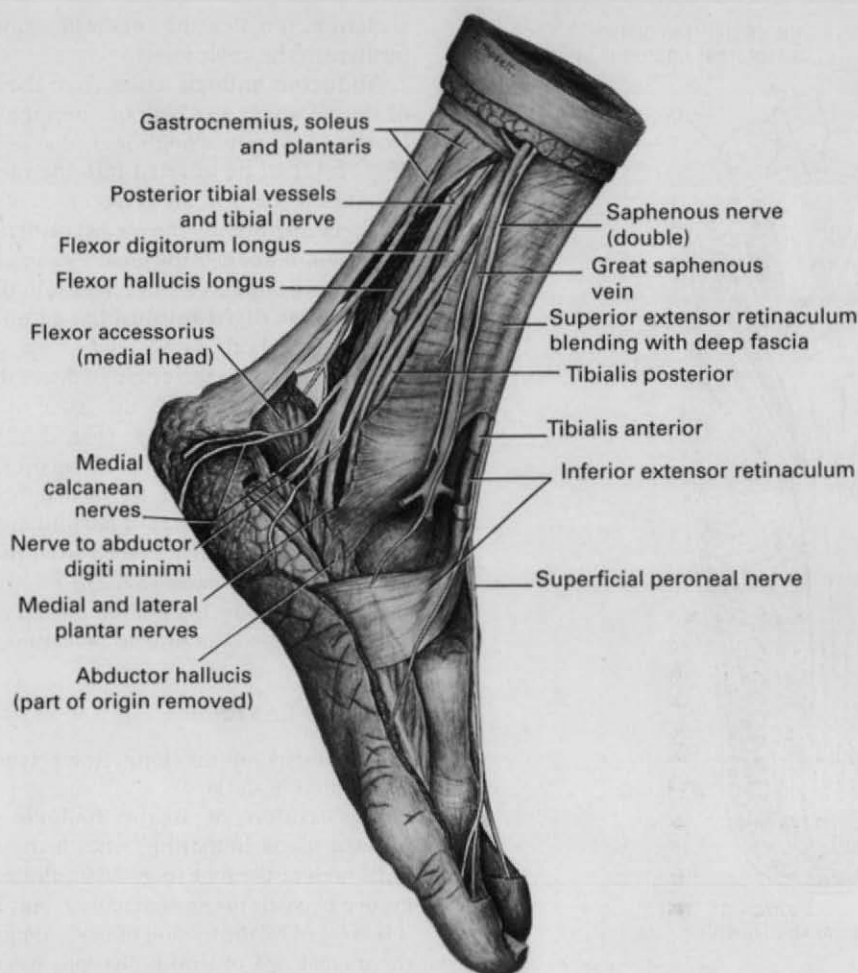


Fig. 3.40 Left foot and ankle from the medial side.

medial and lateral tubercles of the calcaneus and from the back of that bone below the insertion of the tendo calcaneus. It fans out over the sole and is inserted by five slips, into each of the five toes. The digital slips bifurcate for the passage of the flexor tendons and are inserted around the edges of the fibrous flexor sheaths and into the transverse ligaments that bind together the metatarsal heads. From each edge of the plantar aponeurosis a septum penetrates the sole, separating the flexor digitorum brevis from the abductors of big and little toes. The septa are attached to the first and fifth metatarsal bones. The abductors of the big and little toes, lying along the margins of the sole, are covered by deep fascia that is much thinner than the dense plantar aponeurosis.

The **muscular layers** of the sole are much the same

as those of the palm (see p. 104). Four layers are conventionally described. The superficial consists of three short muscles that cover the sole, beneath the plantar aponeurosis. Next lies the second layer, consisting of long tendons to the digits, and their connexions. The third layer consists of the short muscles of the great and little toes; it is confined to the metatarsal region of the foot. The fourth layer consists of both plantar and dorsal interossei and it includes also the tendons of peroneus longus and tibialis posterior. Apart from these last two tendons all pass to the toes, so naturally the shortest muscles lie deepest.

The plantar arteries and nerves lie between the first and second layers. The segmental nerve supply of all the muscles is essentially S2 (compare with T1 for the small muscles of the hand).

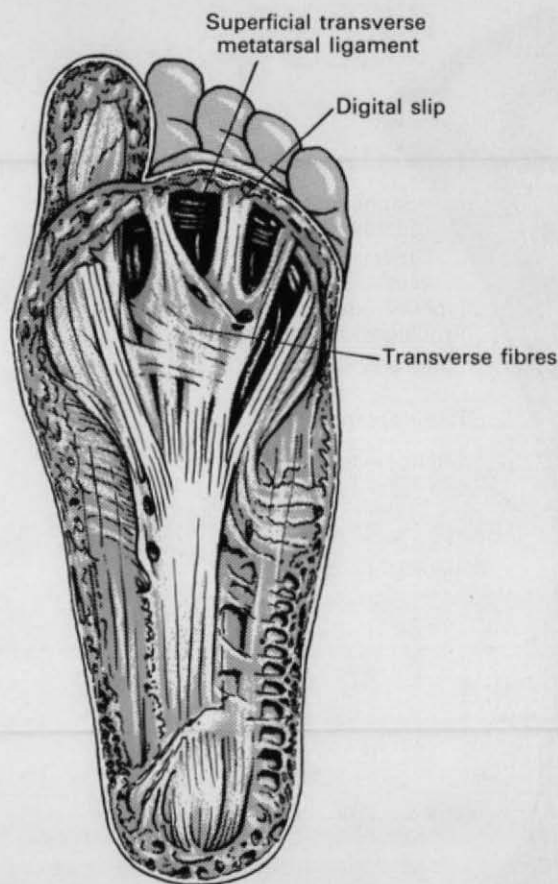


Fig. 3.41 Left plantar aponeurosis.

FIRST LAYER

Three short muscles lie side by side along the sole of the foot. The central of these, *flexor digitorum brevis*, is the counterpart of *flexor superficialis* in the upper limb, and is represented in the palm by the four tendons of that muscle.

Flexor digitorum brevis arises from the medial tubercle of the calcaneus and its fleshy belly lies in contact with the strong central part of the plantar aponeurosis. It divides into four tendons which pass to the lateral four toes. Each tendon enters the fibrous flexor sheath on the plantar aspect of its digit (Fig. 3.42), divides and spirals around the long flexor tendon, and partially reunites in a chiasma before dividing again to be inserted into the sides of the middle phalanx. This is an identical arrangement with that of the *flexor digitorum superficialis*.

Nerve supply. By the medial plantar nerve (S2, 3).

Action. To flex the toes with equal effect in any position of the ankle joint.

Abductor hallucis arises from the medial tubercle of the calcaneus and high up from the deep fascia that overlies it. It runs along the medial margin of the foot (Fig. 3.42) to be inserted into the medial side of the proximal phalanx of the great toe.

Nerve supply. By the medial plantar nerve (S2, 3).

Action. It abducts the great toe, an action largely lost in shoe-wearing races, but retained in the bare-footed.

Abductor digiti minimi has an unexpectedly wide origin, from both *medial and lateral* tubercles of the calcaneus, deep to the origin of *flexor digitorum brevis*. It lies side by side with the latter muscle, along the lateral margin of the foot (Fig. 3.42). Its tendon is inserted into the lateral side of the proximal phalanx of the fifth toe. Some of its medial fibres are usually inserted into the tubercle of the fifth metatarsal bone.

Nerve supply. By a branch from the main trunk of the lateral plantar nerve (S2, 3).

Action. It abducts the little toe, an action, however, which is retained but little in modern man.

SECOND LAYER

This consists of the long flexor tendons and their connexions in the sole.

The **tendon of flexor hallucis longus** passes forward like a bowstring beneath the medial longitudinal arch of the foot (Fig. 3.50). Posteriorly it lies in a groove beneath the sustentaculum tali. Further forward it is crossed by the tendon of *flexor digitorum longus*, to the medial two of whose divisions it gives off a strong slip. It next lies in a groove between the two sesamoids beneath the head of the first metatarsal bone, and finally is inserted into the base of the distal phalanx of the big toe. It is invested by a synovial sheath throughout its whole course in the foot.

The **tendon of flexor digitorum longus** enters the sole on the medial side of the tendon of *flexor hallucis longus*. At its point of division into its four tendons of insertion it crosses superficial to the tendon of *flexor hallucis longus*, which gives a strong slip to the tendons for the second and third toes. At this point it also receives the insertion of *flexor accessorius* (Fig. 3.42). The four tendons pass forwards in the sole deep to those of *flexor digitorum brevis* and after giving off the lumbricals they enter the fibrous sheaths of the lateral four toes. Each tendon perforates the tendon of *flexor digitorum brevis* and passes on to be inserted into the base of the distal phalanx.

Flexor accessorius (*quadratus plantae*) arises by a large medial head which is fleshy and by a small lateral

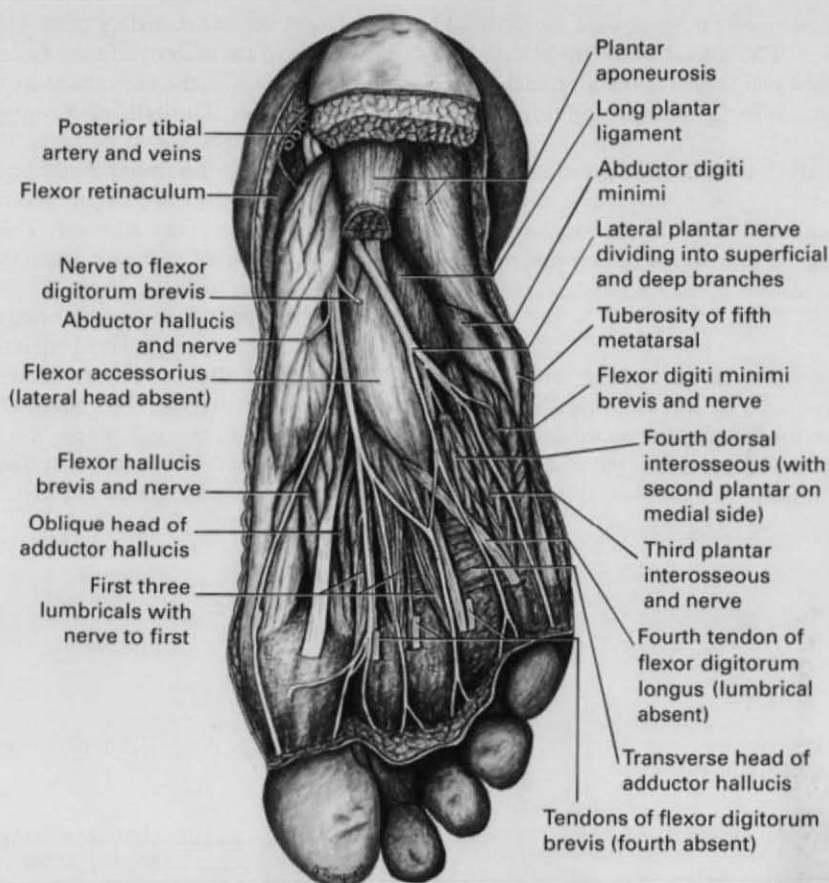


Fig. 3.42 Plantar nerves of the right foot. The deep branch of the lateral plantar nerve curls deeply round the lateral border of flexor accessorius.

head which is tendinous. The medial head arises from the medial surface of the calcaneus almost as far back as its posterior border and from the medial tubercle (Figs 3.40 and 3.42). The lateral head is a flat tendon which arises from the lateral tubercle of the calcaneus and converges to the muscle belly. The posterior part of the long plantar ligament is visible in the triangular interval between the two heads. The muscle belly is inserted into the tendon of flexor digitorum longus at the point where it is bound by a fibrous slip to the tendon of flexor hallucis longus and where it breaks up into its four tendons of insertion.

Nerve supply. By the main trunk of the lateral plantar nerve (S2, 3).

Action. By pulling on the tendons of flexor digitorum longus, it provides a means of flexing the lateral four toes in any position of the ankle joint, particularly in full plantarflexion (here the flexor

digitorum longus is so shortened as to be out of action). It also straightens the pull of the long flexor tendons on the toes.

The muscle is known as *quadratus plantae* in North America, but the name 'accessory flexor' is better, for it indicates the role of the muscle.

The **lumbrical muscles** arise from the tendons of flexor digitorum longus, and pass forward on the medial (tibial, or preaxial, as in the hand) sides of the metatarsophalangeal joints of the lateral four toes (Fig. 3.42). Their tendons lie on the plantar surfaces of the deep transverse ligament of the metatarsal heads and pass dorsally to be inserted into the extensor expansions.

Nerve supply. As in the hand, a lumbrical supplied by the medial plantar (cf. median) nerve is unicipital, one supplied by the lateral plantar (cf. ulnar) nerve is bicipital. In the foot only the first lumbrical is supplied

by the medial plantar nerve; it arises by a single head from its own tendon. The lateral three lumbricals are supplied by the lateral plantar nerve (deep branch) and each arises by two heads from the adjoining sides of the tendons.

Action. The lumbricals maintain extension of the digits at the interphalangeal joints while the flexor digitorum longus tendons are flexing the toes, so that in walking and running the toes do not buckle under.

THIRD LAYER

This consists, like the first layer, of three muscles but they are shorter, confined to the metatarsal region of the foot. Two act on the big toe, one on the little toe.

Flexor hallucis brevis lies against the under surface of the metatarsal bone of the first toe (Fig. 3.43). It

arises from the under surface of the cuboid by a slender slip and from the under surfaces of all three cuneiforms, blending here with the expansions from the insertion of tibialis posterior. The belly of the muscle splits into two parts whose edges are in contact. They are inserted, each by way of a sesamoid bone, into the medial and lateral sides of the base of the plantar surface of the proximal phalanx of the great toe. The medial insertion blends with that of abductor hallucis, the lateral with that of adductor hallucis.

Nerve supply. By the medial plantar nerve (S2,3).

Action. To flex the proximal phalanx of the big toe.

Adductor hallucis has two heads, a large oblique and a small transverse. The oblique head (Fig. 3.43) arises anterior to flexor hallucis brevis, from the long plantar ligament where it roofs over the peroneus longus tendon, and from the bases of the second, third

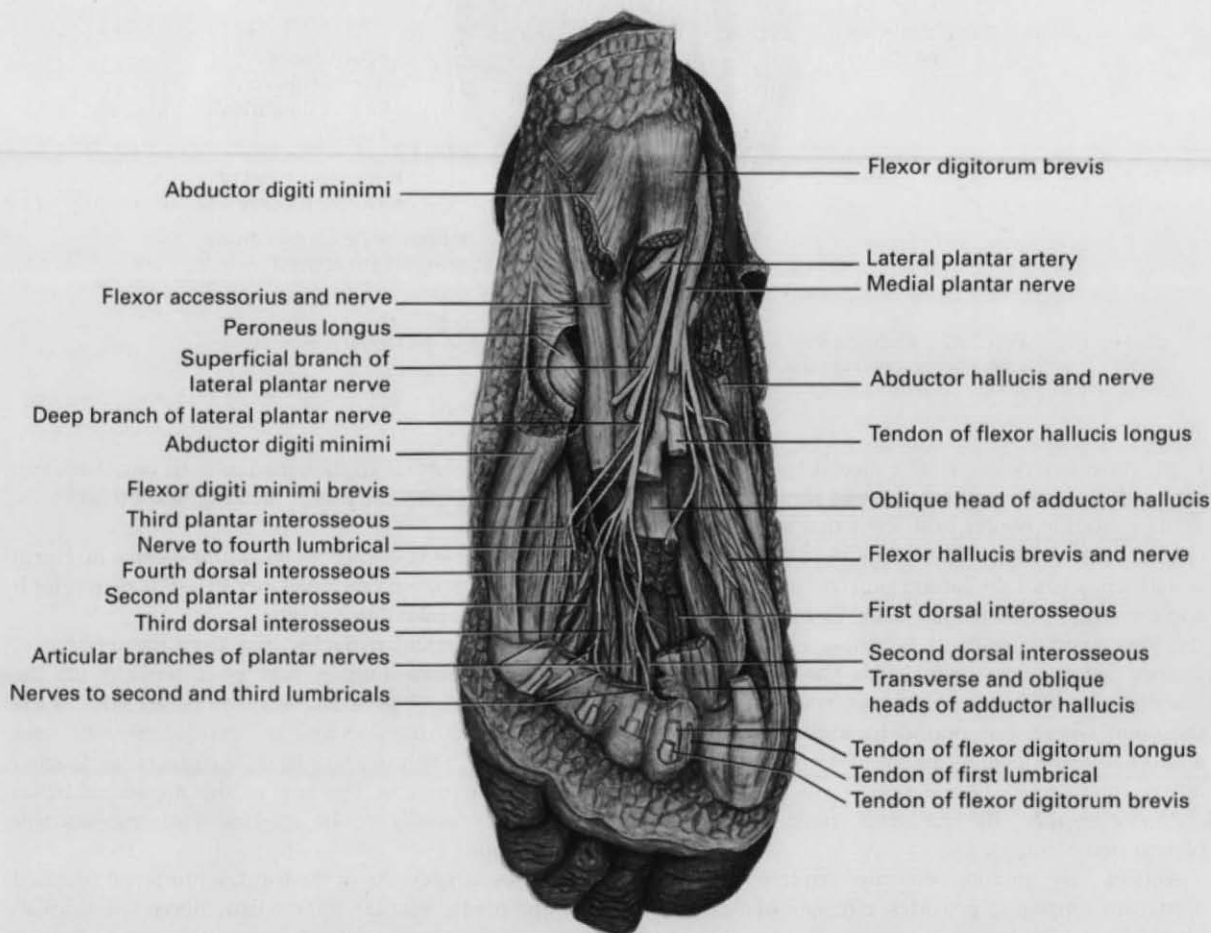


Fig. 3.43 Deep branch of the left lateral plantar nerve.

and fourth metatarsal bones. The slender transverse head (Fig. 3.42) has no bony origin; it arises from the deep transverse ligament and from the under surfaces of the lateral four metatarsophalangeal joints. The two heads unite (Fig. 3.43) in a short tendon which is inserted, with the lateral insertion of flexor hallucis brevis, into the lateral side of the plantar surface of the base of the proximal phalanx of the big toe.

Nerve supply. By the deep branch of the lateral plantar nerve (S2, 3) which sinks into the muscle.

Action. The muscle draws the big toe towards the axis of the metatarsus and thus assists in maintaining the transverse arch.

Flexor digiti minimi brevis arises from the base of the fifth metatarsal bone and the adjoining fibrous sheath of peroneus longus. The muscle belly lies along the under surface of the fifth metatarsal bone (Fig. 3.43) and its tendon is inserted into the base of the proximal phalanx medial to the insertion of abductor digiti minimi.

Nerve supply. By the superficial branch of the lateral plantar nerve (S2, 3).

Action. To assist in flexing the little toe.

FOURTH LAYER

The fourth layer of muscles consists of the interossei in the intermetatarsal spaces. The tendons of tibialis posterior and peroneus longus, lying deeply against the under surface of the tarsus, are conveniently included in this layer.

Interosseous muscles

The actions of the interossei of the foot (Fig. 3.44), as of the hand, are indicated by the formula 'PAD and DAB': the plantar adduct and the dorsal abduct, but with the important difference that the longitudinal axis of the foot has shifted preaxially, and lies along the second metatarsal bone and the phalanges of the second toe. As in the hand, a **plantar interosseous** arises from the metatarsal bone of its own toe, a **dorsal interosseous** arises by two heads from the two metatarsals between which it lies. By use of the formula 'PAD and DAB' the attachments of the interossei may be inferred if memory fails.

The three plantar adducting muscles adduct towards the second toe. The first toe has its own adductor mechanism (oblique and transverse heads of adductor hallucis) so that only the lateral three toes require adducting interossei. The first, second and third plantar interossei, each arising from the metatarsal bone of its own digit with some fibres attached to adjacent

tarsometatarsal ligaments, are inserted by tendons into the medial (tibial or preaxial) sides of the third, fourth and fifth digits. The three tendons pass dorsal to the deep transverse ligament of the metatarsal heads and are inserted chiefly into the bases of the proximal phalanges, though each possesses an additional attachment into the dorsal extensor expansion.

The four dorsal abducting muscles abduct away from the line of the second toe. The big and little toes each possess an abductor muscle. The second requires an abducting muscle on each side while the third and fourth require a single muscle each to abduct the digit laterally, away from the second toe. Each arises from both bones of its own intermetatarsal space and from adjacent tarsometatarsal ligaments. The first is inserted on the big toe side of the second toe, the second, third and fourth on the little toe side of the second, third and fourth toes. The tendons are inserted chiefly into the bones of the proximal phalanges, though each gives an extension also to the dorsal extensor expansion.

The interossei, both plantar and dorsal, are crowded into the intermetatarsal spaces. The first space has the first dorsal interosseous muscle only. The other three spaces contain both dorsal and plantar interossei but in each of them the dorsal is the bulkier muscle, arising from both bones of the space. Note that a view from the plantar aspect of the sole displays as much dorsal as plantar interosseous muscle (Fig. 3.44), but on the dorsum only dorsal interossei are seen (as in the hand).

Nerve supplies. All interossei are supplied by the lateral plantar nerve (S2, 3). Those of the fourth space are supplied by the superficial branch, all the remainder by the deep branch.

Action. The adducting and abducting actions of the interossei (described above) are of little significance in the human foot. It is more important that, like their companions in the hand, they assist the lumbricals in extending the interphalangeal joints (through the extensor expansions) and flexing the metatarsophalangeal joints (by their attachments to the proximal phalanges).

The **tendon of peroneus longus** crosses the sole obliquely (Fig. 3.44). It lies against the posterior ridge, not deeply in the groove, of the cuboid and its bearing surface is protected at the lateral margin of the foot by a sesamoid fibrocartilage which may be ossified. As it crosses the groove of the cuboid it is held in position by the long plantar ligament which is firmly attached to the anterior and posterior ridges to bridge the groove (Fig. 3.48). Emerging from this tunnel the tendon proceeds to its insertion at the base of the first metatarsal and adjoining area on the lateral surface of

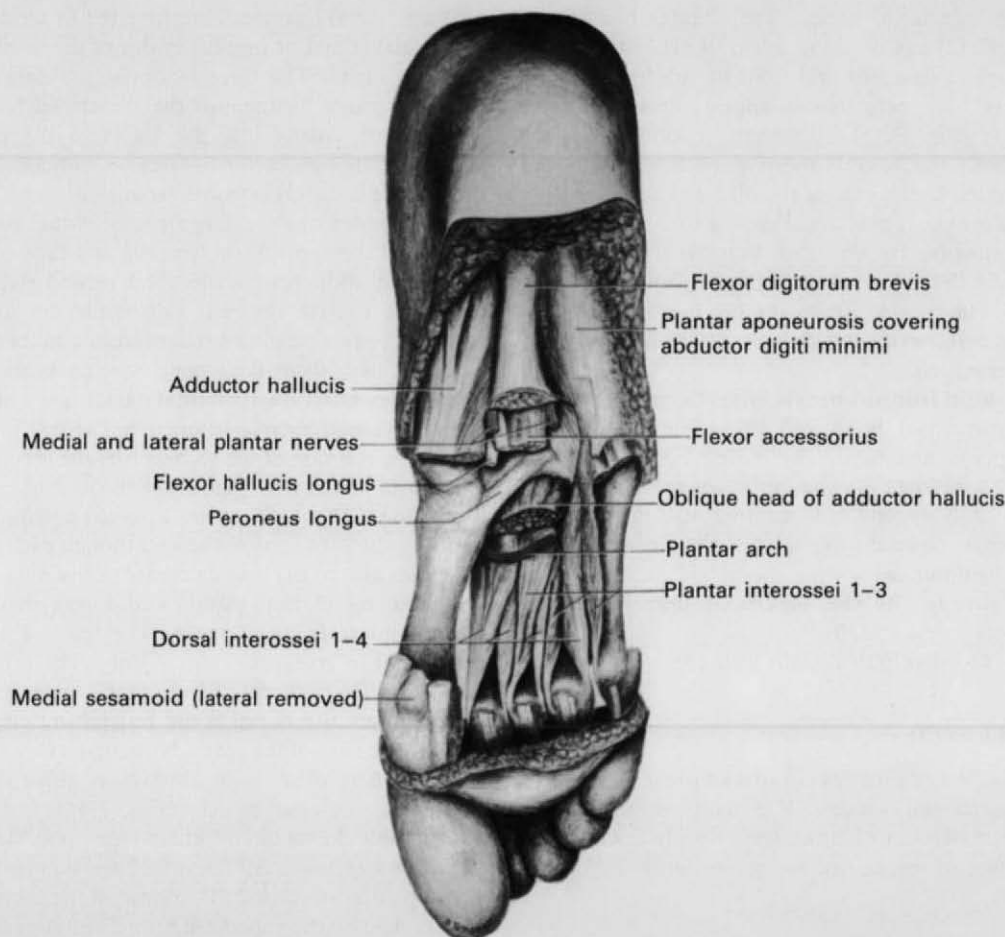


Fig. 3.44 Interossei in the sole of the right foot.

the medial cuneiform. A synovial sheath accompanies it throughout its course.

The **tendon of tibialis posterior** is inserted into the tuberosity of the navicular (Fig. 3.50). It lies above the sustentaculum tali and spring ligament. From its insertion many bands of fibres are traceable to other parts of the foot; usually described as insertions of the muscle they are rather in the nature of ligaments. From the navicular a few pass to the sustentaculum tali; all three cuneiforms, the floor of the groove in the cuboid and the bases of the second, third and fourth metatarsals receive strong bands of fibres.

VESSELS AND NERVES

These are derived from the posterior tibial neurovascular bundle in the calf. The posterior tibial artery and

tibial nerve divide, each into medial and lateral plantar branches, under cover of the flexor retinaculum, the artery higher than the nerve, so that on medial and lateral borders of the sole the *artery is more marginal than the nerve*. Where they cross, the nerve is nearer the skin; and each artery is accompanied by a pair of venae comitantes. The medial plantar nerve is larger than the lateral; it supplies fewer muscles (though their bulk is considerable) than the lateral plantar nerve but it supplies much more skin. The medial plantar artery, on the other hand, is smaller than its fellow; it gives rise to no plantar arch. In the hand there are two palmar arches, a superficial from the ulnar artery, and a deep from the radial artery; but in the foot there is only one plantar arch, derived from the lateral plantar artery.

The neurovascular plane of the sole lies between the first and second layers, upon the long tendons.

The **medial plantar artery** runs forward on the marginal (medial) side of the **medial plantar nerve** (Fig. 3.43) under cover of the muscles of the first layer. Both give off many branches to the sole, which perforate the plantar aponeurosis in the interval between abductor hallucis and flexor digitorum brevis. The artery supplies these two muscles and the structures on the medial side of the foot and its digital supply is restricted practically to the big toe.

The nerve supplies these two muscles, and also the flexor hallucis brevis and the first lumbrical; in addition it gives off digital cutaneous branches that supply the medial three and a half toes on their plantar surfaces and on their dorsal surfaces proximal to the nail beds. Its most lateral cutaneous branch communicates with the neighbouring lateral plantar digital branch (Fig. 3.42) across the plantar surface of the fourth metatarsophalangeal joint, where pressure on the nerve may give rise to the painful condition known as metatarsalgia.

The **lateral plantar artery** crosses the sole obliquely, on the marginal (lateral) side of the nerve, just deep to the first layer of the sole, towards the base of the fifth metatarsal bone.

Both artery and nerve give off cutaneous branches to the sole that perforate the plantar aponeurosis in the interval between flexor digitorum brevis and abductor digiti minimi. The artery gives off a branch that accompanies the superficial branch of the nerve, but its main trunk accompanies the deep branch of the nerve to form the plantar arch. The **plantar arch** curves convexly forwards, across the bases of the fourth, third and second metatarsals and is joined in the proximal part of the first intermetatarsal space by the dorsalis pedis artery.

Perforating branches from the arcuate artery (from dorsalis pedis) join the arch in the proximal ends of the other three interosseous spaces. From the convexity of the plantar arch plantar metatarsal arteries run forwards and bifurcate to supply the four webs and digits. Anterior perforating arteries from the plantar metatarsal arteries reinforce the dorsal metatarsal arteries.

The **veins** accompanying the perforating arteries take most of the blood from the sole and from the interosseous muscles to the dorsal venous arch. The veins among the plantar muscles are now recognized as taking part in a 'sole pump' which is a significant aid to the 'soleal pump' of the posterior compartment of the calf (p. 193).

The **lateral plantar nerve** crosses the sole obliquely just deep to the first layer of muscles (Fig. 3.42). It supplies flexor accessorius and abductor digiti minimi

and sends perforating branches through the plantar aponeurosis to supply skin on the lateral side of the sole. Near the base of the fifth metatarsal bone it divides into superficial and deep branches. The *superficial branch* supplies the fourth cleft and communicates with the medial plantar nerve and, by a lateral branch, supplies the skin of the lateral side and distal dorsum of the little toe. Unlike the superficial branch of the ulnar nerve, this branch supplies three muscles, namely flexor digiti minimi brevis and the two interossei of the fourth space (third plantar and fourth dorsal). The *deep branch* (Fig. 3.43) lies within the concavity of the plantar arch and ends by sinking into the deep surface of the oblique head of adductor hallucis. It gives off branches to the remaining interossei, to the transverse head of adductor hallucis and to the three lateral (bicipital) lumbricals. The branch to the second lumbrical passes dorsal to the transverse head of adductor hallucis and recurves ventrally to enter the lumbrical.

PART 11 ANKLE AND FOOT JOINTS

ANKLE JOINT

The **ankle joint**, properly called the *talocrural joint*, is usually described as being of the hinge variety; but its movements are not quite those of a simple hinge, for the axis of rotation is not fixed but changes between the extremes of plantarflexion and dorsiflexion. The articulating surfaces are covered with hyaline cartilage. The weight-bearing surfaces are the upper facet of the talus and the inferior facet of the tibia. Stabilizing surfaces are those of the medial and lateral malleoli, which grip the sides of the talus. The joint is enclosed in a capsule lined with synovial membrane. The **capsule** is attached to the articular margins of all three bones except the anterior part of the talus, where it is fixed some distance in front of the articular margin, on the neck of the bone. Posteriorly the capsule, on its way up to the tibia, is attached also to the posterior tibiofibular ligament.

The **synovial membrane** is attached to the articular margin of the talus and clothes the intracapsular part of the neck. Elsewhere it is attached to all articular margins, as in any synovial joint. Occasionally the joint cavity extends up a little between tibia and fibula, into the inferior tibiofibular ligament.

Strong medial and lateral **ligaments** strengthen the joint. The **deltoid ligament**, on the medial side, is in two layers. The *deep part* (Fig. 3.45) is narrow,

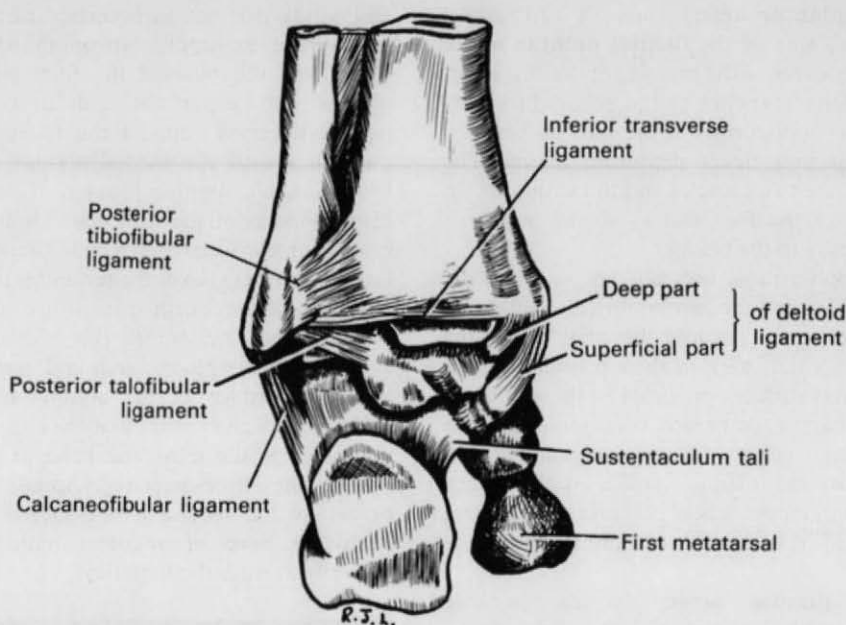


Fig. 3.45 Left ankle and heel from behind.

extending from the tibial malleolus to the side of the talus, inserted there into the concavity below the comma-shaped articular surface. Its shape is rectangular. Only the *superficial part* is triangular, like a delta. It fans downwards from the borders of the tibial malleolus and its lower margin has a continuous attachment from the medial tubercle of the talus (a weak band) along the edge of the sustentaculum tali and spring ligament (very strong) to the tuberosity of the navicular (a weak band) (Figs 3.45 and 3.48).

On the lateral side there are three separate bands, radiating from the lateral malleolus, which are collectively and commonly but not officially called the *lateral ligament*. Anterior and posterior bands pass to the talus, the intermediate band to the calcaneus. The **anterior talofibular ligament** (Fig. 3.46) joins the anterior border of the lateral malleolus to the neck of the talus. It is a flat band. The **calcaneofibular ligament** (Fig. 3.46) is a rounded cord extending from the front of the tip of the malleolus down and back to the lateral surface of the calcaneus. The strong **posterior talofibular ligament** (Fig. 3.45) lies *horizontally* between the malleolar fossa and the lateral tubercle of the talus. Above it lies the **posterior tibiofibular ligament**, whose lower part (sometimes called the *inferior transverse ligament*) articulates with the talus. In plantarflexion these two ligaments lie edge to edge,

but in dorsiflexion they diverge like the blades of an opening pair of scissors.

The blood supply of the capsule and ligaments is derived from anterior and posterior tibial arteries and the peroneal artery, and the nerve supply is by the deep peroneal and tibial nerves.

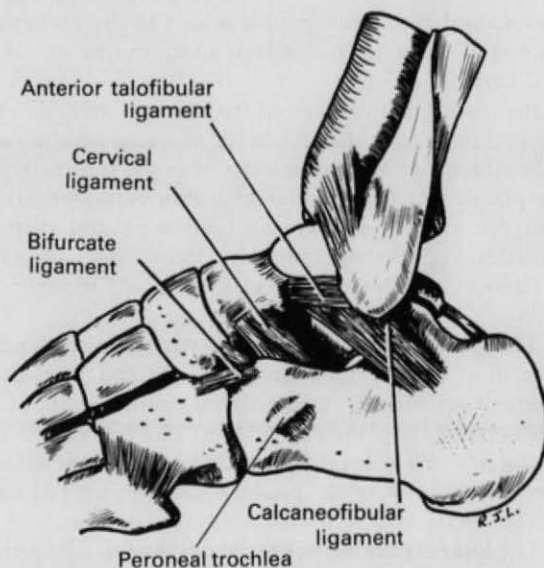


Fig. 3.46 Left ankle from the lateral side.

Movements

Examine a talus. Its upper facet, slightly concave from side to side, is convex anteroposteriorly. It is broad in front and narrow behind. The lateral facet, while gently concave from above downwards, is convex from front to back in most bones; it articulates with the lateral malleolus. The upper and medial surfaces of the talus are in contact with the tibia and its medial malleolus in all positions of the joint. The lateral malleolus adapts itself to the lateral surface of the talus; this involves rotary and lateral movements of the lower end of the fibula, which cause reciprocal movements at the upper end of the bone, in the superior tibiofibular synovial joint.

In full plantarflexion the smallest area of the talus is in contact with the tibia, but even in this position the amount of inversion and eversion possible at the ankle joint is very small indeed. For all practical purposes the ankle may be regarded as a true hinge joint. The axis of rotation is not horizontal, but slopes downwards and laterally. It passes through the lateral surface of the talus just below the apex of the articular triangle and through the medial surface at a higher level, just below the concavity of the comma-shaped articular area. It passes through the malleoli just above their apices. In truth, though the fact is of no practical application, the axis changes during movement, for the upper convexity of the talus is not the arc of a circle, but rather of an ellipse. The obliquity of the axis involves a slight movement resembling inversion in full plantarflexion, and the reverse, resembling slight eversion, in full dorsiflexion, but these apparent movements are not of true inversion and eversion (see below).

Plantarflexion (up to 50°) is produced most powerfully and essentially by gastrocnemius and soleus. This gives the basic thrust for propulsion (p. 211). The long flexor tendons and the long and short peronei all have a secondary action of flexion on the ankle joint. Dorsiflexion (extension, up to 25°) is produced by the tibialis anterior and peroneus tertius, aided on occasion by the toe extensors.

Surgical approach

The ankle joint can be exposed from the front between the tendons of extensor hallucis and digitorum longus, avoiding damage to the intervening deep peroneal nerve and anterior tibial vessels. For approach behind the medial malleolus the tendons of tibialis posterior and flexor digitorum longus are displaced forwards, while on the lateral side the peroneus longus and brevis can be displaced forwards to reach the capsule behind

the lateral malleolus. For needle puncture the joint can be entered in front of the lateral malleolus and lateral to the tendon of peroneus tertius, or in front of the medial malleolus medial to tibialis anterior. The joint line should be defined by moving the foot.

TARSAL JOINTS

By far the most important joints in the tarsus are those between the talus, calcaneus and navicular and between the calcaneus and cuboid.

Examine the articulated bones of a foot, preferably together with a separate talus, calcaneus and navicular. On the under surface of the talus there are two separate joints. At the back is the **talocalcaneal joint**, where the convex posterior articular facet on the upper surface of the calcaneus (Fig. 3.49) articulates with the concave articular facet on the under surface of the talus. In front of this is a more complicated joint, with part of the under surface of the head of the talus articulating with the upper surface of the sustentaculum tali and body of the calcaneus and the spring ligament (Fig. 3.49), and the front of the head of the talus articulating with the navicular (Fig. 3.47). The whole joint with its single synovial cavity is called **talocalcaneonavicular** and, because of the way the bones articulate, it can be said to have two parts: *talocalcaneal* and *talonavicular*. It is the talocalcaneal part of the talocalcaneonavicular joint that forms the second joint underneath the talus.

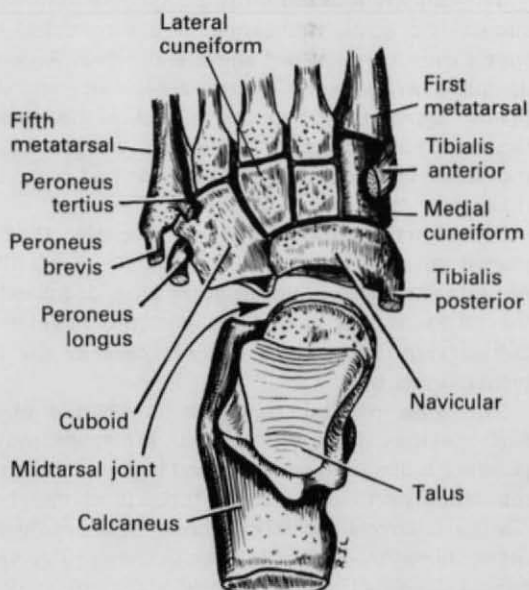


Fig. 3.47 Bones of the left foot from above, separated at the midtarsal joint. The insertions of all tendons producing inversion and eversion of the foot are in front of this joint.

The **calcaneocuboid joint** is a separate joint between the front of the calcaneus and the back of the cuboid; this and the talonavicular part of the talocalcaneonavicular joint form what is usually called the **midtarsal joint** (Fig. 3.47).

There is an unfortunate complication in the use of the adjective 'subtalar' to describe one or more joints beneath the talus. Anatomically, subtalar joint is an alternative name for the talocalcaneal joint (the single one at the back of the calcaneus), but orthopaedic surgeons often use 'subtalar joint' as a functional term to include both the talocalcaneal joint and the talocalcaneonavicular part of the talocalcaneonavicular joint, i.e. it is a composite term for the two joints beneath the talus, and is where most of the movements of inversion and eversion occur. It is essential to appreciate that while the *lateral* part of the midtarsal joint (the calcaneocuboid) is a separate joint with its own capsule, the medial part of the midtarsal joint (the talonavicular part of the talocalcaneonavicular) is not a separate joint but is only the anterior part of a continuous synovial cavity that extends backwards below the head of the talus, and includes the spring ligament, the anterior part of the upper surface of the calcaneus, and the sustentaculum tali. The head of the talus, in other words, is a ball which articulates with a socket composed of the posterior concavity of the navicular (part of the midtarsal joint) and the spring ligament and sustentaculum tali (part of the clinical 'subtalar joint').

The **calcaneocuboid joint** is a synovial joint whose surfaces are gently undulating. It is surrounded by a simple capsule, thickened above and below. Accessory ligaments on its plantar surfaces are the long and short plantar ligaments, and the lateral limb of the bifurcate ligament strengthens it medially. Simple gliding movement takes place during inversion and eversion of the foot.

The **short plantar ligament** (properly called the plantar calcaneocuboid) is a thick bundle which fills in the adjacent hollows in front of the anterior tubercle of the calcaneus and behind the posterior ridge of the cuboid (Fig. 3.48). It is covered over by the long plantar ligament.

The **long plantar ligament** covers the plantar surface of the calcaneus (Fig. 3.48). It extends from the posterior tubercles (i.e. medial and lateral tubercles) on the calcaneus to the anterior tubercle of that bone. Thence it covers the short plantar ligament, and its deeper fibres are attached to the posterior ridge of the cuboid. Its superficial fibres bridge the groove of the cuboid, making a fibrous roof over the peroneus longus tendon, and are attached to the anterior ridge of the cuboid and extend forwards to the bases of the central

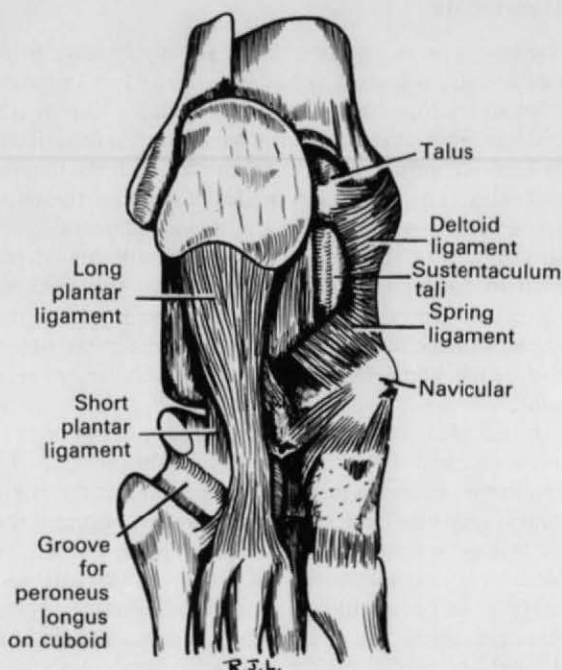


Fig. 3.48 Plantar ligaments of the left foot. On the medial side the deltoid ligament of the ankle joint fuses with the spring ligament.

three metatarsal bones. It is covered by flexor accessorius, and its posterior part is visible in the gap between the medial fleshy and lateral tendinous heads of that muscle.

Various other smaller but stronger interosseous plantar ligaments unite adjacent bones and help to support the arches of the foot.

The **talocalcaneonavicular joint** is a synovial joint of the ball and socket variety. The ball is the head of the talus (Fig. 3.47) and the socket comprises the two bones and two ligaments (Fig. 3.49). The bones are the navicular and calcaneus. The posterior surface of the navicular has an articular surface which is concave reciprocally with the anterior convexity of the head of the talus.

The anterior end of the upper surface of the calcaneus has a concave facet, and the sustentaculum tali a similar one (the two are often fused into a single concavity) for articulation with the inferior convexity of the head of the talus. On the head of the talus, between its navicular and calcaneal surfaces, lies cartilage that articulates with neither bone. Here the talus articulates with the spring ligament medially and the calcaneonavicular limb of the bifurcate ligament laterally. All these structures are enclosed in a single capsule. One end of

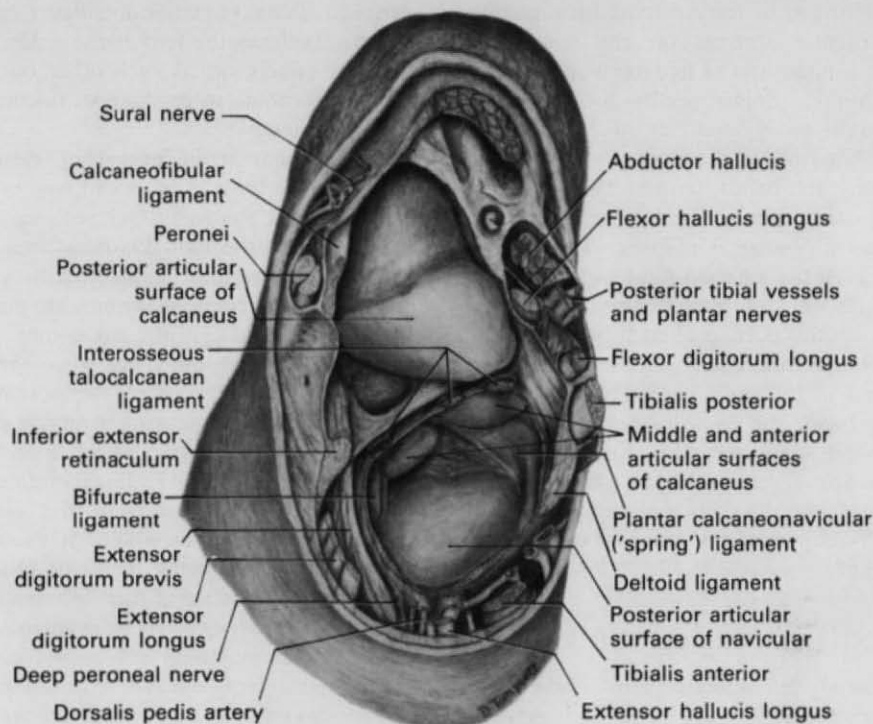


Fig. 3.49 Joints beneath the right talus exposed by removal of the talus.

the capsular sleeve is attached to the neck of the talus around the articular margin on the head. The other end of the sleeve is attached along the upper surface of the navicular, the medial edge of the spring ligament, the posterior limits of the articular facets on sustentaculum tali and body of calcaneus, the medial limb of the bifurcate ligament and so back to the upper surface of the navicular. The socket of the joint is closed below by the spring and bifurcate ligaments. Between the two lies a pad of fat, covered with synovial membrane, that acts as a swab to spread synovial fluid on the moving head of the talus (like the Haversian fat pad in the acetabulum).

The **bifurcate ligament** arises from the upper surface of the calcaneus just behind the anterior margin of that bone, under cover of the extensor digitorum brevis muscle at the front of the tarsal sinus. From the single origin two limbs diverge slightly from each other. The medial limb is attached to the navicular, near the inferolateral part of its articular margin. It forms part of the socket in which the head of the talus lies and gives attachment to the capsule of the talocalcaneonavicular joint. It is always present. The lateral limb of the bifurcate ligament is often absent. It is extracapsular, and is attached to the upper surface of the cuboid, being no

more than an accessory ligament of the calcaneocuboid joint.

The **plantar calcaneonavicular (spring) ligament** is a very strong band that joins the whole thickness of the edge of the sustentaculum tali to the navicular between its tuberosity and the articular margin (Fig. 3.48). Its upper surface, which extends to the articular margins of both bones, articulates with the anteroinferior part of the head of the talus, and bears a plaque of fibrocartilage for this purpose. Its lower fibres extend well under the sustentaculum tali and lie almost transversely across the foot (Fig. 3.49). It consists, like ligaments in general, of collagenous tissue and despite its common name 'spring ligament' it is not elastic.

The **talocalcaneal joint** lies behind the talocalcaneonavicular joint. It is a synovial joint, oval in shape, with its long axis lying obliquely from posteromedial to anterolateral. The under surface of the talus is concave from side to side, reciprocally with the convex articular facet on the calcaneus (Fig. 3.62). The capsule and synovial membrane are attached to the articular margin.

The **tarsal sinus** lies obliquely between the talocalcaneonavicular joint and the talocalcaneal joint. It is a

cylindrical canal formed by the semicylindrical grooves between the articular surfaces on the two bones (Fig. 3.62), and it opens out at its lateral end like the broad end of a funnel. (Sometimes the medial tunnel-like part is called the *tarsal canal*, but this is not official nomenclature). Anteriorly and posteriorly the sinus is occupied by strong, flat bands, forming the *interosseous talocalcaneal ligament*, whose fibres diverge upwards from each other in V-shaped manner. They are in reality thickenings of the adjacent joint capsules. They leave *smooth* marks on each bone alongside the articular facets. The central portion of each bony gutter is perforated by vascular foramina.

The lateral end of the sinus is occupied by a very strong cord-like band, the *cervical ligament*. It leaves *smooth* facets on calcaneus and talus. Further laterally lies part of extensor digitorum brevis where it arises from the calcaneus, and the sinus is closed in finally by the stem of the Y-shaped inferior extensor retinaculum (Figs 3.46 and 3.62).

INVERSION AND EVERSION OF THE FOOT

After the midtarsal and subtalar joints have been studied, the movements of inversion and eversion which they allow can be appreciated. The ability to invert and evert the foot confers on man a corresponding ability to walk across *uneven* surfaces that slope sideways, and loss of this power produces an appreciable disability when progressing across rough ground. A similar disability is noted in walking on *smooth* surfaces if these slope sideways, for such progression requires the upper foot to be everted and the lower inverted. Moreover, in turning at speed the movements are essential, in order to lean sideways on a foot whose sole is flat on the ground.

Mostly these inversion-eversion movements are performed on a foot anchored to the ground, with the leg bones and thus the whole body inverting and everting above it. It is difficult to analyse the movements from a fixed foot, so the analysis is best made with the foot free of the ground. The malleoli lock the talus, and the suspended foot inverts and everts around it. (Inversion is sometimes described as a combination of adduction and supination, eversion combining abduction with pronation, but authorities disagree about the definitions of these terms as applied to the foot.)

The movement of **inversion** (raising the medial border of the foot) is produced, self-evidently, by any muscle that is attached to the medial side of the foot. Tibialis anterior and tibialis posterior are responsible, assisted by extensor and flexor hallucis longus on

occasion. Tibialis anterior dorsiflexes and tibialis posterior plantarflexes the foot at the ankle joint and these opposite effects cancel each other out when the two muscles combine to produce an uncomplicated inversion of the foot.

The movement of **eversion** (raising the lateral border of the foot) is produced, self-evidently, by any muscle that is attached to, or pulls upwards upon, the lateral side of the foot. Peroneus longus, brevis, and tertius are responsible. The former two, whose tendons pass behind the lateral malleolus, are plantarflexors, the last is a dorsiflexor, of the ankle joint. These opposite effects cancel each other out when the three muscles combine to produce a simple eversion of the foot.

All the muscles producing inversion and eversion are attached to the fore part of the foot, anterior to the midtarsal joint (Fig. 3.47). It is therefore evident that in both inversion and eversion the *beginning* of the movement must occur wholly at the midtarsal joint, and that only when the bones of this joint are fully 'wound up' by tension of their ligaments is the rotatory force transmitted, passively by ligaments, to the subtalar joints. In fact, relatively little movement is possible at the midtarsal joint, and *most of the full range of inversion and eversion occurs at the joints beneath the talus*.

The calcaneus and cuboid are firmly connected by the long and short plantar ligaments, which limit the range of mobility at the midtarsal joint; when they and the spring ligament of the midtarsal joint are taut they transmit the rotatory force to the calcaneus. This bone then rotates (i.e. inverts or everts) under the talus, which is firmly wedged against the tibia between the malleoli and cannot therefore be inverted or everted.

The axis of inversion-eversion movement is along an oblique line (Fig. 3.50) passing from the lateral tubercle of the calcaneus upwards, forwards and medially through the neck of the talus, bisecting the medial part of the tarsal sinus. The lines of pull of the muscles lie at right angles to this obliquity, so that the muscles act to the best mechanical advantage. The balanced actions of these muscles combine in different patterns to produce ordered movements of the ankle and tarsal joints.

Mechanically there are four lines of pull:

- (1) Tibialis anterior, which inverts (and therefore adducts) the foot at the tarsal joints and dorsiflexes the foot at the ankle joint.
- (2) Peroneus tertius, which everts (and therefore abducts) the foot at the tarsal joints and dorsiflexes the foot at the ankle joint.
- (3) Tibialis posterior, which inverts (and therefore adducts) the foot at the tarsal joints and plantarflexes the foot at the ankle joint.

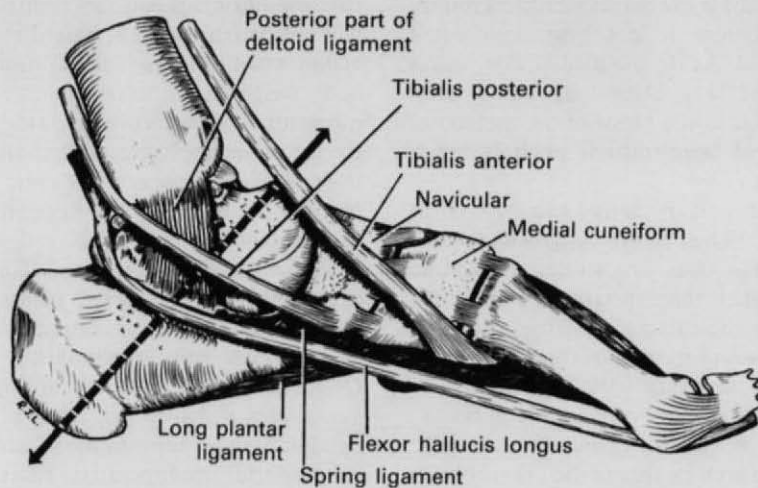


Fig. 3.50 Left foot from the medial side, with the axis of inversion and eversion indicated by the interrupted arrow. The inverting tendons pull at right angles around the axis. The everting peroneal tendons act in a similar way on the lateral side (Fig. 3.37).

(4) Peroneus longus and brevis, which evert (and therefore abduct) the foot at the tarsal joints and plantarflex the foot at the ankle joint.

These four combine in groups of two to produce their common movement and cancel out their opposing movements. Thus result dorsiflexion (1 and 2), inversion (1 and 3), eversion (2 and 4) and plantarflexion (3 and 4) of the foot as a whole, though it must be remembered that there is an added powerful mechanism (antigravity and propulsive) producing plantarflexion of the foot as a whole, namely the pull on the heel by soleus and gastrocnemius through the tendo calcaneus.

TARSOMETATARSAL JOINTS

The osteology of the tarsal bones and the anatomy of the tarsometatarsal joints are considered in the account of the osteology of the foot (pp. 229 and 233).

The **metatarsus** is much more rigid than the metacarpus. The first tarsometatarsal joint possesses its own capsule and synovial membrane and is capable of some movement in a vertical plane to conform with movements in the medial longitudinal arch of the foot, and it becomes hyperextended in flat foot; but the joint movements in no way compare with those of the carpometacarpal joint of the thumb and no opposition of the big toe is possible. The second tarsometatarsal joint is immobile, the base of the metatarsal being

firmly fixed between the anterior ends of the medial and lateral cuneiforms. This is a result of the shifting of the axis of the foot towards its medial side, and the second toe forms the line for adduction and abduction of the digits. The immobility of the second metatarsal and the slenderness of its shaft are contributory factors in 'spontaneous' fracture ('march fracture') of this bone.

The **first metatarsophalangeal joint** is the site of hallux valgus. The big toe has no dorsal extensor expansion nor fibrous flexor sheath; its long tendons are held in position by strands of deep fascia. If the phalanges become displaced laterally and the fibrous bands give way, the pull of extensor hallucis longus, like that of extensor hallucis brevis, becomes oblique to the long axis of the toe and tends to increase the deformity.

The **interphalangeal joints** are similar to those of the hand, with capsules and collateral ligaments (p. 120).

SUPPORTING MECHANISM OF THE FOOT

Examine the bones of an accurately articulated foot, a lateral radiograph of the foot and the imprint of a wet foot on the bathroom floor. The heel, lateral margin of the foot, the ball of the foot (the part underneath the metatarsal heads) and the pads of the distal phalanges touch the ground. The medial margin of the foot arches up between the heel and the ball of the big toe, forming a visible and obvious **medial longitudinal arch**. The

lateral margin of the foot is in contact with the ground, but its constituent bones do not bear with equal pressure on the ground. As on the medial side, so on the lateral side, there is a bony longitudinal arch extending from the heel to the heads of the metatarsal bones, but the **lateral longitudinal arch** is much flatter than the medial.

The constituent bones of the arches can be seen in the articulated foot. The *medial longitudinal arch* consists of calcaneus, talus, navicular, the three cuneiform bones and their three metatarsal bones. The pillars of the arch are the tuberosity of the calcaneus posteriorly and the heads of the medial three metatarsal bones anteriorly. The *lateral longitudinal arch* consists of calcaneus, cuboid and the lateral two metatarsal bones.

The *transverse arch* is, in reality, only half an arch, being completed as an arch by that of the other foot. It consists of the *bases* of the five metatarsal bones and the adjacent cuboid and cuneiforms. The *heads* of the five metatarsal bones lie flat upon the ground and can scarcely be described as taking part in the transverse arch, though the first and fifth heads bear more weight than the others.

The factors maintaining the integrity of the arches of the foot are identical with those responsible in any joint of the body, namely, bony, ligamentous and muscular, but their relative importance is different in the three arches.

Medial longitudinal arch

No bony factor is responsible for maintaining the stability of this arch. The head of the talus is supported on the sustentaculum tali, but this is a negligible factor. Ligaments are important, but are *inadequate alone* to maintain the arch. The most important ligament is the plantar aponeurosis, stretching like a tie beam or bowstring between the supporting pillars of the arch. If it is shortened by extension of the toes, especially the big toe, it draws the pillars together and so heightens the arch. Next in importance is the spring ligament, for it supports the head of the talus. If it stretches it allows the navicular and calcaneus to separate and so the head of the talus, the highest point of the arch, sinks lower between them. All the interosseous ligaments, especially those which hold the talus and calcaneus together at their articulating surfaces, are of assistance in maintaining the arch.

Muscles are indispensable to the maintenance of the medial longitudinal arch, for if they are paralysed, or weakened beyond a certain point, the ligaments alone are unable to maintain the arch.

Examine a living foot. The arch cannot be pressed

flat; the ligaments are too strong. Static body weight will not flatten the arch; indeed the muscles are not in action when standing still. Consider the inertia of the body weight to be overcome at the take-off and the momentum to be absorbed in landing. In each of these the forces are vastly greater than the mere weight of the body. The arch now acts like a semielliptic spring. If the muscles are too weak the ligaments eventually stretch and flat foot results.

The most efficient means of maintaining an arch such as this is to tie its two pillars together. The most important muscular supporting structures are therefore those which run longitudinally beneath the arch. *Overwhelmingly efficient in this respect is the tendon of flexor hallucis longus* (Fig. 3.50). The muscle is the bulkiest of those beneath the soleus in the calf and from its powerful multipennate mass the tendon runs beneath the sustentaculum tali and thence passes straight forward, below the arch, to lie between the sesamoid bones on the metatarsal head before it reaches its insertion at the distal phalanx of the big toe. This is not only the bulkiest of the deep calf muscles, but it can spare a slip to assist the pull of its weaker sister, flexor digitorum longus, and it is highly significant that this slip *acts only on the tendons to the second and third toes*, the remaining members of the medial longitudinal arch.

Thus *flexor hallucis longus* acts as a bowstring along the medial longitudinal arch from the sustentaculum tali to the medial three digits. It is not called into play during short periods of standing, for generally the weight is borne well back on the heel and the pads of the toes are not pressed on the ground. Meanwhile the ligaments support the arch. But during prolonged standing the ligaments 'tire', and relief is obtained by pressing the pads of the toes to the ground. During movements of propulsion and during landing on the feet the inertia and momentum of the body weight throw a vastly greater strain on the arch, and this strain is taken up by the contraction of the flexor hallucis longus muscle and the tension of its tendon.

The short muscles in the first layer that are inserted into the medial three toes (abductor hallucis, and the medial half of flexor digitorum brevis) likewise assist in maintaining the arch. The attachment of some interosseous muscle fibres to ligaments in the region of the tarsometatarsal joints may help to stabilize these joints when rigidity is required.

The tendons of *tibialis anterior* and *peroneus longus* are inserted into the same two bones (medial cuneiform and first metatarsal bone) and they are often compared to a sling that supports the longitudinal arches of the foot, like a skipping rope pulled up beneath the instep

of a shoe. But there is a significant difference—the tendons are not free like a skipping rope to slide under the foot, but are fixed to bone and they exert opposite effects upon the medial longitudinal arch. Tibialis anterior, by the upward pull of its tendon, may have some slight influence in maintaining the medial longitudinal arch, but the peroneus longus tendon has the reverse effect, as is so well seen in the everted *flat* foot of peroneal spasm in children. The lowest point in the tendon is at its sesamoid fibrocartilage, where it bears on the cuboid; from this point it rises further from the ground as it slopes across to its insertion. Its pull tends to evert and abduct the foot and *lower the medial side of the foot*.

Tibialis anterior and tibialis posterior have a significant influence on the arch, but mechanically different from the bowstring effect of the longitudinally directed muscles and tendons in the sole. They act by their tendency to invert and adduct the foot, in other words to raise the medial border from the ground, and have no direct pull tending to approximate the pillars of the arch, and are consequently less important factors in maintaining its integrity.

Lateral longitudinal arch

No bony factor contributes to the stability of this arch, but ligaments play a relatively more important part than in the case of the medial arch.

The plantar aponeurosis in its lateral part acts as a bowstring beneath the arch and the plantar ligaments are also significant. The short plantar ligament is very thick, filling the adjacent concavities of calcaneus and cuboid. The long plantar ligament, though a thinner layer, extends from the heel to both ridges of the cuboid and the metatarsal bases and helps to maintain the slight concavity of the lateral arch.

The peroneus longus tendon, tending to depress the medial longitudinal arch, at the same time pulls upwards on the lateral longitudinal arch and is the most important single factor in maintaining its integrity. The tendons of flexor digitorum longus to the fourth and fifth toes (assisted by flexor accessorius) and the muscles of the first layer of the sole (lateral half of flexor digitorum brevis and abductor digiti minimi) also assist strongly, by preventing separation of the pillars of the arch.

Transverse arch

The intermediate and lateral cuneiforms are wedge-

shaped, and in this single respect the bones are adapted to the maintenance of the transverse arch of the foot. The lateral cuneiform overhangs the cuboid and thus rests on it to some extent. But the medial cuneiform is wedge-shaped the wrong way for an arch, and it is evident that bony factors in fact play but little part in maintaining the transverse arch. The lateral cuneiform bears on the cuboid from above, but not with much pressure because the medial longitudinal arch has its own supports.

The ligaments that bind together the cuneiforms and bases of the five metatarsal bones are much more important, and the most important factor of all is the tendon of peroneus longus, the pull of which tends to approximate medial and lateral borders of the foot across the sole. At the heads of the metatarsal bones a shallow arch is maintained by the deep transverse ligament of the metatarsal heads, by the transverse fibres that bind together the digital slips of the plantar aponeurosis and, perhaps, by the transverse head of the adductor hallucis muscle, but the last is a very slender band.

PROPULSIVE MECHANISM OF THE FOOT

If the foot were entirely rigid it would serve as a propulsive member by plantarflexion at the ankle joint and, indeed, the contraction of soleus and gastrocnemius is the chief factor responsible for propulsion in walking, running and jumping. But the propulsive action of these great muscles of the calf is enhanced by arching of the foot and flexion of the toes. The sequence of events in walking is usually described as four phases: heel-strike, support (stance or weight-bearing), toe-off (push off) and swing. The weight of the foot is taken successively on the heel, lateral border, and the ball of the foot, and the last part to leave the ground is the anterior pillar of the medial longitudinal arch and the medial three digits. In running the heel remains off the ground, but the take-off point is still the anterior pillar of the medial longitudinal arch.

While the heel is rising from the ground the medial toes are gradually extended. The extended big toe pulls the plantar aponeurosis around the first metatarsal head and so heightens the arch; at the same time it elongates the flexor hallucis longus and flexor digitorum longus muscles, and this increases the force of their subsequent contraction.

Contraction of the toe flexors, long and short, increases the force of the take-off by the pressure of the toes on the ground. Contraction of the long flexors also aids plantarflexion at the ankle joint.

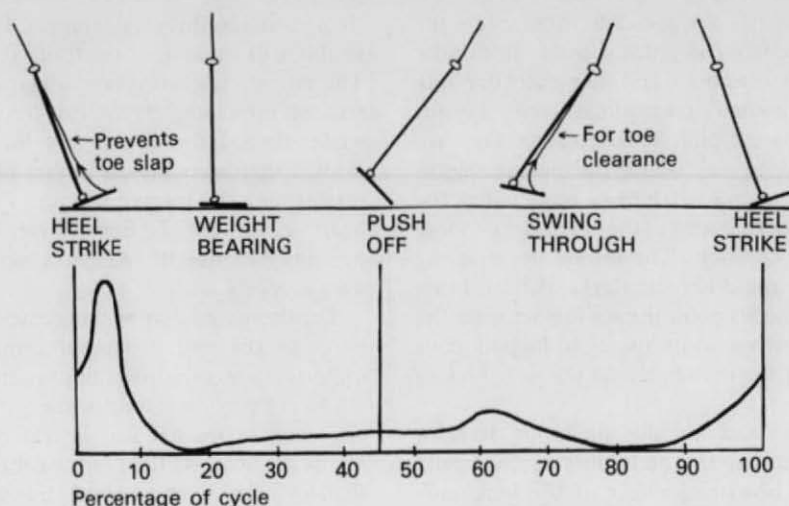


Fig. 3.51 Phasic action of the pretibial muscle group during walking. The contraction during heel-strike (shock-absorbing) is much greater than that needed for toe clearance during the swing-through phase.

The most powerful muscle acting in this way is the flexor hallucis longus, which acts on the big toe through its tendon of insertion and on the second and third toes by the slip it gives to the flexor digitorum longus. The short flexor muscles of the sole strongly assist the long flexors in heightening the arch and in flexing the toes—the lumbricals prevent the toes from buckling under when pulled upon by flexor digitorum longus. The propulsive force so produced adds greatly to that of the soleus and gastrocnemius. The tendo calcaneus plantarflexes a very mobile, not a rigid, foot. If the tendo calcaneus is activated by a 'bottom gear' and 'top gear' mechanism (soleus and gastrocnemius), the flexors of the tarsus and toes provide an 'overdrive'.

SHOCK-ABSORBING MECHANISM OF THE FOOT

When landing at speed, as for example from a height, the toes and then the forefoot take the first thrust of the weight before the heel strikes the ground. It is, in fact, the reverse time sequence of taking off at maximum speed. But even in quiet walking, with heel and toe sequence, muscles play an essential part in absorbing the shock of landing. At the moment of heel strike the pretibial group, notably tibialis anterior, contract as they elongate to lower the forefoot more gently to the ground (Fig. 3.51).

PART 12

SUMMARY OF LOWER LIMB INNERVATION

CUTANEOUS INNERVATION

The segmental supply (dermatomes) of the lower limb has been considered on page 24. The cutaneous nerves have been described in the preceding pages but for convenience are summarized here (Figs 3.52 and 3.53).

The skin of the buttock receives fibres that run down from the subcostal and iliohypogastric nerves, the posterior rami of the first three lumbar and first three sacral nerves, and the perforating cutaneous nerve, with an upward contribution from the posterior femoral cutaneous nerve. The latter supplies a long strip down the back of the limb to below the popliteal fossa, with lateral and medial femoral cutaneous nerves on either side and a contribution of variable extent from the obturator nerve on the medial side. On the front of the thigh, the ilioinguinal nerve extends below the inguinal ligament, with subcostal and genitofemoral elements on either side, and the intermediate femoral cutaneous nerve down the middle overlapping with its medial and lateral namesakes and the obturator.

The skin of the front of the knee receives branches from the medial femoral cutaneous nerve, the lateral cutaneous nerve of the calf which extends some way

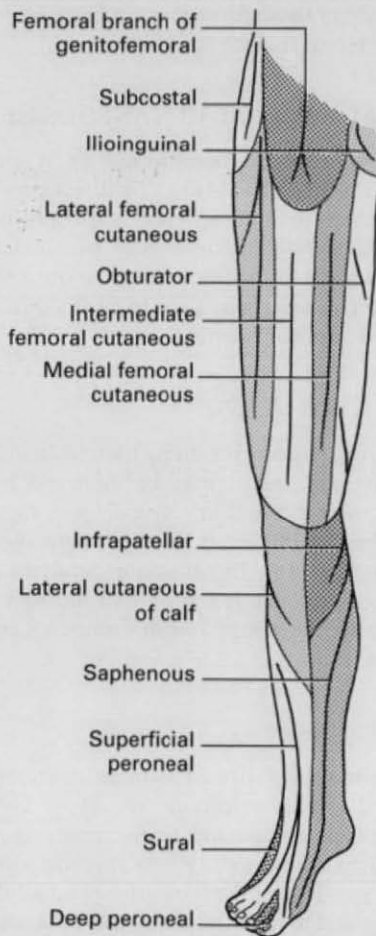


Fig. 3.52 Cutaneous nerves of the front of the right lower limb.

down the outside and back of the leg, and medially the saphenous nerve which reaches as far as the metatarsophalangeal joint of the great toe. The superficial peroneal extends over the front of the lower leg and dorsum of the foot, with the deep peroneal supplying the first toe cleft. The sural nerve takes over from the lateral cutaneous nerve of the calf on the lateral side of the back of the leg and extends along the lateral side of the foot to the little toe. Calcaneal branches of the tibial nerve supply the heel, with medial and lateral plantar nerves on the sole in front of the tibial area of supply; the medial plantar, like the median nerve in the hand, usually supplies three and a half digits.

MUSCULAR INNERVATION

The segmental innervation of lower limb muscles has

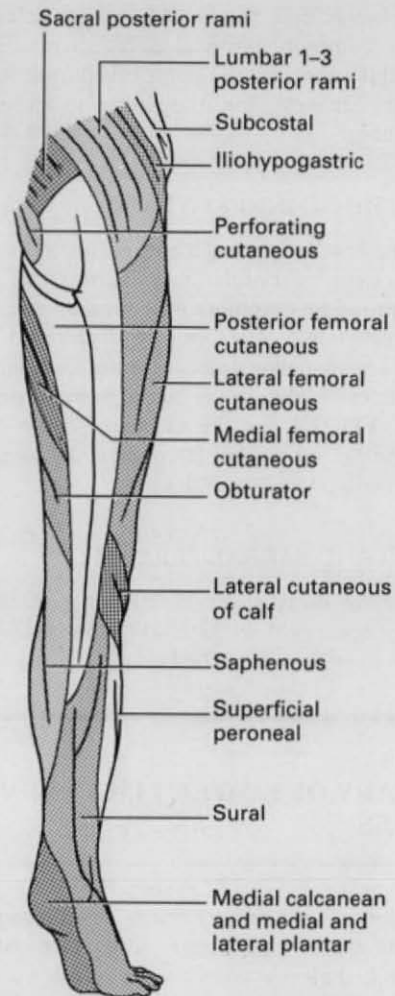


Fig. 3.53 Cutaneous nerves of the back of the right lower limb.

been considered on page 25. In the thigh the anterior compartment is supplied by the femoral nerve and the adductor group by the obturator nerve. The tibial part of the sciatic nerve is the nerve of the posterior compartment, with only the short head of biceps supplied by the common peroneal part. In the gluteal region, the inferior gluteal nerve innervates gluteus maximus with the other two glutei receiving their supply from the superior gluteal which also supplies tensor fasciae latae. The short lateral rotator muscles behind the hip have their own nerves, with the obturator externus supplied by the obturator nerve which also supplies part of adductor magnus (hence it has a double innervation with the sciatic). The tibial nerve is the nerve of the flexor compartment of the leg

and its plantar branches supply the muscles of the sole. The common peroneal nerve divides into the superficial peroneal for the peroneal compartment and the deep peroneal for the anterior or extensor compartment.

SYMPATHETIC INNERVATION

As with the brachial plexus, a grey ramus communicans joins each nerve root of the lumbar and sacral plexuses to the appropriate ganglion of the sympathetic trunk so that postganglionic fibres can be distributed to each nerve. The preganglionic fibres for the lower limb have come from cell bodies in the lateral horn of spinal cord segments T11–L2, for the ultimate supply of blood vessels and (as far as skin is concerned) sweat glands and arrectores pilorum muscles.

LUMBAR AND SACRAL PLEXUSES

Summaries of these plexuses, including all the lower limb branches, begin on page 414, after the abdomen and pelvis have been described.

PART 13

SUMMARY OF LOWER LIMB NERVE INJURIES

Peripheral nerve injuries are much less common in the lower limb than in the upper; although damage to a whole brachial plexus can occur, this is most unusual in the case of the lumbar and sacral plexuses. The commonest injury is to the common peroneal nerve, and the main features of this and other nerve lesions are summarized below, together with notes on the more common exposures if exploration and repair are required.

FEMORAL NERVE

Since the nerve breaks up into a sheaf of branches as soon as it enters the thigh (p. 156), it is more subject to damage by penetrating injuries of the lower abdomen than of the limb. Pelvic masses such as a haematoma or neoplasm may affect it, and it has been known to be damaged by catheterization of the femoral artery. In a complete lesion extension of the knee by the quadriceps will be lost, with some weakness of hip flexion. There is anaesthesia over the front of the thigh; with lesions that cause pain in the nerve the pain may extend as far as the

medial side of the foot (saphenous branch). Test for the action of rectus femoris (p. 157).

LATERAL FEMORAL CUTANEOUS NERVE

The nerve may be compressed as it passes from abdomen to thigh (p. 146) or by direct pressure below and medial to the anterior superior iliac spine, producing meralgia paraesthetica which is recognized by paraesthesia in the upper lateral part of the thigh. If necessary the nerve may have to be freed from the iliac fascia and inguinal ligament.

OBTURATOR NERVE

Because of its deep position, trauma to this nerve is extremely rare, but it may be damaged by obstetric procedures or involved in pelvic disease, e.g. an ovarian tumour may cause pain in the skin on the medial side of the thigh (p. 146). In obturator paralysis the loss of adduction at the hip is not noticed during walking but when sitting the affected limb cannot be crossed over the other.

SCIATIC NERVE

The commonest cause of damage is (regrettably) by misplaced gluteal injections (p. 166). Other causes include pelvic disease and severe trauma to the hip (in 7% of dislocations and 16% of fracture-dislocations). There is paralysis of the hamstrings and all the muscles of the leg and foot (supplied by the tibial and common peroneal nerves). Paralysis of the hamstrings may be difficult to test because of pain but foot drop will be obvious, and there will be anaesthesia below the knee but *not on the medial side* of the leg due to the supply here from the saphenous branch of the femoral nerve. There will only be anaesthesia on the back of the thigh if the posterior femoral cutaneous nerve is damaged at the same time; the sciatic nerve through its two main branches only supplies skin below knee level. Test for plantarflexion and dorsiflexion.

Surgical approach. The sciatic nerve is explored by exposure at the lower border of gluteus maximus and medial to the long head of biceps; from there it can be followed upwards or downwards.

COMMON PERONEAL (FIBULAR) NERVE

Direct trauma or pressure by plaster casts at the neck of the fibula (p. 173) make this the most commonly damaged nerve in the lower limb. Foot drop is the most obvious sign, due to paralysis of the extensor muscles

supplied by the deep peroneal branch (p. 188). This results in a high-stepping gait to ensure that the toes do not scrape along the ground. Peroneus longus and brevis in the lateral compartment will also be affected, being supplied by the superficial peroneal branch. Anaesthesia in a common peroneal nerve lesion extends over the lower lateral part of the leg and the dorsum of the foot (p. 189), but as with radial nerve lesions in the upper limb there may be little or no sensory loss. Test for dorsiflexion.

Surgical approach. The nerve can be exposed by following it down from behind the biceps tendon on the lateral side of the popliteal fossa.

TIBIAL NERVE

Damage to this nerve is uncommon. The main effect is paralysis of the calf muscles. Test for standing on tiptoe.

Surgical approach. The nerve is easily exposed in the popliteal fossa; it can be followed lower down by splitting gastrocnemius and soleus vertically in the midline.

SAPHENOUS NERVE

The lower part of this nerve, in front of the medial malleolus (p. 185), is subject to damage during varicose vein surgery by becoming included in ligatures—a cause of possible litigation.

PART 14 OSTEOLOGY OF THE LOWER LIMB

HIP BONE

This is formed of three bones, which fuse in a Y-shaped epiphysis involving the acetabulum. The pubis and ischium together form an incomplete bony wall for the pelvic cavity; their outer surfaces give attachment to thigh muscles. The ilium forms the pelvic brim between the hip joint and the joint with the sacrum; above the pelvic brim it is prolonged, broad and wing-like, for the attachment of ligaments and large muscles. The anterior two-thirds of the projecting ilium, thin bone, forms the iliac fossa, part of the posterior abdominal wall. The posterior one-third, thick bone, carries the auricular surface for the sacrum and, behind this, is prolonged for strong sacroiliac ligaments which bear the body weight. The outer surface of the ilium gives

attachment to buttock muscles. The ischium and pubis together lie in approximately the same plane; the plane of the ilium is at nearly a right angle with this.

Note the correct anatomical position of the bone. The pubic tubercle and anterior superior iliac spine lie in the same vertical plane, and the upper border of the symphysis pubis and the ischial spine lie in the same horizontal plane.

Lateral surface of the hip bone

This (Fig. 3.54) is best studied after the anatomy of the thigh and buttock is familiar.

The hip joint socket, the **acetabulum** ('vinegar-cup'), is a concave hemisphere whose axis is not strictly horizontal but is directed also downwards and slightly backwards along the axis of the femoral neck. Its inferior margin is lacking (Fig. 3.54), so the vinegar would run out of the cup. The margins of this **acetabular notch**, curved in outline, are lined with hyaline cartilage, which continues as a wide band inside the concave surface of the acetabulum. It is widest above, opposite the notch. This wide upper part of the articular surface is the weight-bearing area, lying like a cap over the femoral head (*remember the anatomical position*, Fig. 5.50, p. 373). The articular surface does not quite reach the rim of the acetabulum, nor does it floor in the whole concavity. The non-articular bone in the acetabular fossa is paper-thin and translucent. This bone is prolonged down below the acetabular notch as a narrow rim skirting the obturator foramen. Here pubis and ischium meet at the low rounded elevation about a third of the way down the anterior margin of the greater sciatic notch (see below). Pubis and ilium meet at the anterior pole of the acetabulum (the place is indicated by the iliopubic eminence). Ilium and ischium meet just above the posterior pole of the acetabulum. Thus the broad weight-bearing part of the articular surface is carried *entirely by the ilium*.

The acetabular notch is filled by the *transverse ligament*, thus completing the concavity of the articular surface (Fig. 3.17). Beyond the articular margin the rim of the acetabulum gives attachment to the fibrocartilaginous **acetabular labrum**. The capsule of the hip joint is attached to the acetabular labrum and to the surrounding bone; inferiorly it is attached to the transverse ligament. The *ligament of the femoral head* (ligamentum teres) is attached to the transverse ligament, not to the bone of the acetabulum. Synovial membrane is attached to the concave inner margin of the articular surface, whence it covers the Haversian fat pad in the acetabular fossa and is continued along the ligamentum teres to the fovea on the femoral head.

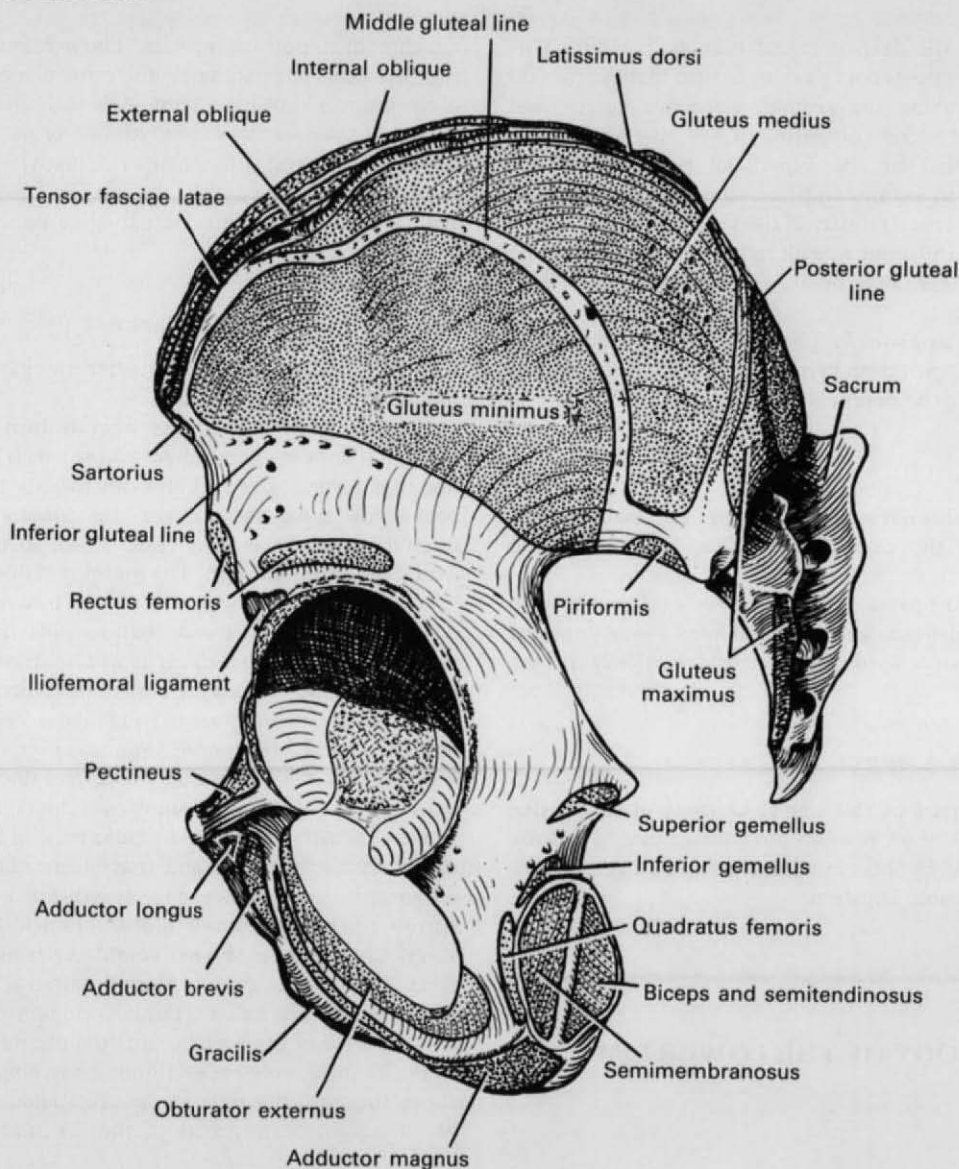


Fig. 3.54 Left hip bone from the lateral side and behind.

Synovial membrane is likewise attached around the convexity of the articular margin and to the outer margin of the transverse ligament, whence it lines the hip-joint capsule down to the femur.

The **outer surface of the ilium**, above the acetabulum, rises wedge-shaped along an anterior border to the **anterior superior iliac spine**. Behind the acetabulum it passes up as a thick bar of weight-bearing bone, curves back to form the **greater sciatic notch**, and continues to a posterior margin that lies between

posterior inferior and **posterior superior iliac spines**. The upper border of the ilium, the iliac crest (see below), between anterior and posterior superior spines, has a bold upward convexity and is at the same time curved from front to back in a sinuous bend. The anterior part of the crest is curved outwards, and the external lip is built up into a more prominent convexity 5 cm behind the anterior superior spine; this is the **tubercle** of the iliac crest and forms the most lateral part of the bony pelvis, but not the highest part which is

7.5 cm (3 in) behind the tubercle. The line between the highest points of the two iliac crests indicates the supracristal plane, and passes through the spine of L4 vertebra, the landmark for counting vertebral spines (e.g. for lumbar puncture, p. 575).

The **gluteal surface** of the ilium is undulating, convex in front and concave behind, in conformity with the curvature of the iliac crest. It shows three curved gluteal lines. The most prominent is the *posterior gluteal line*, a low crest passing down from the iliac crest to the front of the posterior inferior spine. The area behind this line gives attachment to part of gluteus maximus. The *middle gluteal line* is a series of low tubercles coming from the iliac crest 2 cm behind the anterior superior spine; it is convex upwards, curving back just below the tubercle of the iliac crest and then downwards towards the greater sciatic notch. Gluteus medius arises from the ilium between this and the posterior gluteal line, up to the outer lip of the iliac crest. The *inferior gluteal line* is less prominent. It curves from below the anterior superior spine towards the apex of the greater sciatic notch. Tensor fasciae latae arises from the gluteal surface just below the iliac crest, between anterior superior spine and tubercle. Below this the area between the middle and inferior gluteal lines is occupied by the attachment of gluteus minimus. Below the inferior gluteal line is an area of multiple vascular foramina, then a narrow non-perforated strip along the upper margin of the acetabulum for the reflected head of rectus femoris (Fig. 3.17).

The fusion of ilium and ischium is marked by a rounded elevation between the acetabulum and the greater sciatic notch. Above this the ilium forms the major part of the notch. Piriformis emerges here, almost filling the notch and arising in part slightly from its upper margin.

The **anterior border** of the ilium shows a gentle S-bend. Its upper narrow part gives attachment to sartorius, at the anterior superior spine and for a finger's breadth below this. The lower half of this border is projected into the **anterior inferior iliac spine**. This shows a prominent oval facet for the straight head of rectus femoris. Below the facet is a smoother area for the iliofemoral ligament, which is attached also somewhat behind this, above the acetabular margin (Fig. 3.13).

The **posterior border** of the ilium is a rounded bar of bone between the posterior superior and posterior inferior spines (Fig. 6.82, p. 553). It gives attachment to the sacrotuberous ligament. The posterior superior iliac spine makes a characteristic dimple in the skin of the buttock at the level of the second piece of the sacrum.

The posterior part of the **iliac crest** is thicker than

the rest. Running forward from the posterior superior spine is a ridge which is traceable into the external lip at the upper end of the posterior gluteal line. External to the ridge the bevelled surface of the iliac crest continues down to the gluteal surface behind the posterior gluteal line. Gluteus maximus arises from the whole of this area.

In the articulated pelvis the ridge along the posterior part of the iliac crest is seen to be in line, below the posterior superior iliac spine, with the transverse tubercles of the lowest three sacral vertebrae (Fig. 6.82, p. 553). Along the ridge and these transverse tubercles the posterior lamella of the lumbar fascia is attached. The aponeurotic origin of latissimus dorsi is fused with the posterior lamella along the ridge, but the muscle itself extends forward of this along the external lip of the iliac crest, nearly halfway to the anterior superior spine (Fig. 2.5, p. 58). Internal to the ridge and its attached posterior lamella of lumbar fascia the iliocostalis part of erector spinae arises along a visible strip of non-perforated bone. Between this strip and the auricular surface the convex face of the bone shows lines of massed tubercles for the attachment of the strong sacroiliac ligaments (Fig. 3.55).

At the lateral margin of iliocostalis the strong iliolumbar ligament is attached to the iliac crest. Quadratus lumborum arises from the iliolumbar ligament and extends lateral to this to arise in continuity from a visible smooth strip that extends to a point one-third of the way forward from the posterior superior spine. This point is commonly marked by a low tubercle, for the attachment of the conjoined layers of the lumbar fascia that enclose quadratus lumborum (p. 358). In the anatomical position of the bone this is the *highest part of the iliac crest*. From here the internal oblique and transversus abdominis muscles are attached side by side. The internal oblique is attached along the centre of the crest, the transversus to the inner lip of the crest, both extending to the anterior superior spine. External oblique is attached to the outer lip of the iliac crest in its anterior half; the gap between it and latissimus dorsi forms the base of the lumbar triangle (p. 296). The inguinal ligament, attached to the anterior superior spine, extends across to the pubic tubercle. The fascia lata of the thigh is attached along the whole length of the external lip of the iliac crest, splitting to enclose the narrow origin of tensor fasciae latae, and splitting also around gluteus maximus, where its deep layer is attached to the posterior gluteal line.

The **body of the pubis**, quadrilateral in shape, is projected laterally as a **superior ramus** which joins the ilium and ischium at the acetabulum and an **inferior ramus** which fuses with the ischium below

the ischial ramus sometimes shows as a low ridge; it is halfway between the ischial tuberosity and the pubic crest.

The pubic crest gives origin to rectus abdominis and, in front of this, pyramidalis. The narrow linea alba is attached to the fibrous tissue of the pubic symphysis, not to bone, but lateral to this the conjoint tendon is attached over these muscles to the front of the pubic crest, across to the pubic tubercle and, in continuity, along the sharp pectineal line for about 2 cm. This same extent of the pectineal line receives also the upper margin of the lacunar ligament. The periosteum of the pectineal line lateral to this is thickened by the pectineal ligament (of Cooper) (Fig. 5.10, p. 303). Pectineus arises deep to the lacunar ligament, from just below the pectineal line, between pubic tubercle and iliopectineal eminence. The lateral prominence of the obturator crest, near the acetabular margin, gives attachment to the pubofemoral ligament. The pubic tubercle receives the attachment of the inguinal ligament and its so-called reflected part, which is really the posterior crus from the opposite side. The lateral crus of the superficial ring is attached with the inguinal ligament to the pubic tubercle. The medial crus, in front of the conjoint tendon, is inserted into the front of the pubic crest alongside the symphysis (Fig. 5.3, p. 297).

The rounded tendon of adductor longus arises from the front of the body of the pubis, in the angle between the pubic crest and symphysis; bone spurs may be found at this attachment (rider's bone). Below it the linear origin of gracilis extends down along the margin of the everted crest of the inferior ramus to reach the ischial ramus. Deep to adductor longus and gracilis the adductor brevis arises from the body of the pubis. Extending up along the inferior ramus the pubic fibres of adductor magnus arise deep to gracilis, and deeper still is the obturator externus. These muscles leave no distinguishing marks on the bone; their extents of origin are indicated in Figure 3.13. The fascia lata is attached by its deep lamina to the pectineal line over the surface of pectineus (p. 150), and below the pubic tubercle along the front of the body of the pubis to the everted crest. It encloses adductor longus and gracilis, and separates them from the external genitalia in the superficial perineal pouch. Colles' fascia is attached to the pubis alongside the fascia lata.

Like the pubis the **ischium** is an L-shaped bone, and the two lie in the same plane. An upper thick portion of the ischium, the body, joins with pubis and ilium at the acetabulum and extends down to the ischial tuberosity (see below); it supports the sitting weight. A lower, thinner bar, the **inferior ramus**, joins the inferior ramus of the pubis to enclose the obturator foramen.

Behind the acetabulum observe again the low elevation at the line of fusion of ischium and ilium. At the margin of the acetabulum, where the capsule of the hip joint is attached, the fibres of the ischiofemoral ligament sweep from this upper part of the ischium upwards to encircle the capsule around the neck of the femur as the zona orbicularis. More medially the upper part of the body of the ischium completes the lower part of the greater sciatic notch. Here the sciatic nerve, with the nerve to quadratus femoris deep to it, lies on the ischium. This site of emergence of the nerve into the buttock lies one-third of the way up from the ischial tuberosity to the posterior superior iliac spine.

The **spine** of the ischium projects medially to divide the greater from the lesser sciatic notch. The sacrospinous ligament is attached to its margins and tip, converting the **greater sciatic notch** into the greater sciatic *foramen*. The pudendal nerve lies on the ligament just medial to the spine. The internal pudendal vessels cross the tip, while the nerve to obturator internus lies on the base of the spine. The superior gemellus takes origin from the spine. The **lesser sciatic notch** lies between the spine and the ischial tuberosity (Figs 3.20 and 5.67, p. 405). It is bridged by the sacrotuberous ligament, which with the sacrospinous ligament converts the *notch* into the lesser sciatic *foramen* (Fig. 5.51, p. 374). Obturator internus emerges through this foramen into the buttock, and the internal pudendal vessels and nerve pass forward into the perineum. The lesser sciatic notch is floored in life by thickened periosteum, grooved by tendinous fibres on the deep surface of the muscle (Fig. 3.55), and lubricated by a bursa. The inferior gemellus arises from the upper margin of the ischial tuberosity, above the hamstrings (Fig. 3.54).

The **ischial tuberosity** is a rugged prominence whose convex posterior surface is divided transversely by a low ridge. An oval smooth area above this is divided by a vertical ridge into two areas, a lateral and a medial (Figs 3.20 and 3.54). Semimembranosus tendon is attached to the lateral area, semitendinosus and the long head of biceps to the medial area.

Between semimembranosus area and obturator foramen the lateral surface gives a vertical linear origin, 3 cm long, to quadratus femoris, which leaves no mark on the bone. Below the transverse ridge the ischial tuberosity shows a longitudinal crest; this supports the sitting body. The fascia lata of the thigh is attached to this ridge. The lateral bevelled surface here gives origin to the fibres of the hamstring part of adductor magnus (p. 159). The medial bevelled surface receives the sacrotuberous ligament. The ischial tuberosity curves forward from the rugged weight-bearing part into the

slender inferior ramus. Adductor magnus has a continuous origin along this ramus up to the pubic part of the muscle.

The **obturator foramen** is ringed by the sharp margins of the pubis and ischium, those of the pubis overlapping each other in a spiral to form the obturator sulcus. The obturator membrane is attached to the margin of the foramen, but not to the obturator groove. Obturator externus arises from the outer surface of the membrane, a little of the ramus of the ischium and a good deal from the pubis (Fig. 3.13).

Medial surface of hip bone

This is best studied (Fig. 3.55) when the pelvic walls (p. 373) and perineum (p. 400) are understood.

The pelvic brim is made by the top of the pubic crest and the pectineal line, continued up along the rounded border of the ilium (called the arcuate line) to the top of the auricular surface. This curved pelvic brim slopes up at 60°. Below the brim lies the pelvic cavity, above it is the iliac fossa in the abdominal cavity.

On the **inner surface of the ilium** the iliocostalis area and the lines of tubercles on the ligamentous area have already been examined during the study of the outer surface. The **auricular area** really is ear-shaped; it extends from the pelvic brim to the posterior inferior iliac spine. Its surface undulates gently from convex above to concave below and is roughened by numerous tubercles and depressions. It is covered with hyaline cartilage and forms an almost immobile synovial joint with the ala of the sacrum. The capsule and synovial membrane are attached to the articular margin. In later years fibrous bands often join the articular surfaces within the joint space.

The **iliac fossa** is a gentle concavity in the ala of the ilium in front of the sacroiliac joint and its ligaments. Its deepest part, high in the fossa, is composed of paper-thin translucent bone. Iliacus arises, up to the inner lip of the iliac crest, over the whole area down to the level of the anterior inferior iliac spine. The lower one-third of the fossa is bare bone, separated by a large bursa from the overlying iliacus. The fibres of iliacus converge to pass over a broad groove between the iliopubic eminence and the anterior inferior spine. The iliacus fascia is attached around the margins of the muscle: to the iliac crest, the arcuate line and iliopubic eminence (and to the inguinal ligament). Psoas major passes freely along the pelvic brim and crosses the eminence. The 'psoas' bursa deep to it is the iliacus bursa already mentioned. The psoas fascia is attached to the arcuate line and the iliopubic eminence. Psoas minor, when

present, has a tendon which flattens out to be inserted into the pelvic brim at the eminence.

The body and superior ramus of the inner surface of the **pubis** are bare bone, with no attachments. The abnormal obturator artery and/or vein cross behind the ramus and the obturator nerve lies in contact with the ramus in the obturator groove. Levator ani (pubococcygeus part) is attached to the junction of body and inferior ramus level with the lower border of the symphysis. Medial to this are the attachments of the puborectalis sling and the levator prostatae (pubovaginalis) muscle (Fig. 5.54, p. 376). More medially the puboprostatic (pubovesical in the female) ligaments are attached at this level. The inferior ramus thus lies in the perineum. Immediately below the symphyseal surface the subpubic ligament is attached; the deep dorsal vein of the penis (clitoris) lies in the midline below it. Extending down from the symphyseal surface is a ridge of bone to which the perineal membrane is attached. External to this is the everted margin already noted. Here the crus of the corpus cavernosum is attached, with the ischiocavernosus muscle. Between the perineal membrane and the obturator foramen the inferior ramus forms the wall of the anterior recess of the ischioanal fossa. Here the dorsal nerve and artery of the penis (clitoris) pass forwards below levator ani, and here the bone gives attachment to fibres of sphincter urethrae. At the margin of the obturator foramen the obturator internus muscle is attached (see below).

The inner surface of the **body of the ischium** is very gently concave. From its posterior border projects the prominent ischial spine. This divides the greater from the lesser sciatic notch. To it are attached the coccygeus muscle and the white line that gives attachment to the pelvic floor (levator ani, Fig. 5.52, p. 374). Between the ischial spine and tuberosity the lesser sciatic notch is grooved by the tendinous fibres on the deep surface of obturator internus. The grooves and ridges are made more prominent in the fresh bone by thickening of the periosteum. As the ischial tuberosity curves forwards into the ramus it is characterized by a falciform ridge. This ridge and the rough area below it receive the sacrotuberous ligament and its falciform process. Obturator internus arises from the body of the ischium and the area above it up to the arcuate line on the ilium (pelvic brim) to the margin of the greater sciatic notch, from the obturator membrane below the obturator sulcus, from the obturator margin of the inferior ramus of the pubis and from the ramus of the ischium down to the falciform ridge (Fig. 5.62, p. 395). A gap in the origin extends up under the muscle from the lesser sciatic notch (Fig. 3.55) and here a bursa lies on the bare bone beneath the muscle. The fascia over obturator internus

is attached to bone at the margins of the muscle. The pudendal canal on the obturator internus fascia lies just above the falciform ridge on the ischial tuberosity (Fig. 5.67, p. 405). The transverse muscles of the perineum are attached at the anterior extremity of the ramus.

Sex differences

These can be surveyed in the articulated pelvis (p. 373). The female pelvis is made roomier by changes in the hip bone and the isolated bone should be surveyed from behind forwards. The ala of the ilium has been drawn out to widen the female pelvis; the greater sciatic notch is near a right angle in the female, much less in the male, and the female bone may show a preauricular sulcus below the arcuate line. The female ischial spine lies in the plane of the body of the ischium; the male spine is inverted towards the pelvic cavity. The female obturator foramen is triangular, the male foramen is oval in outline. The *surest single feature* is, however, that the distance from the pubic tubercle to the acetabular margin is greater than the diameter of the acetabulum in the female, equal or less in the male bone.

Ossification

The bone develops in cartilage. Three primary centres appear, one for each bone, near the acetabulum. The centre for the weight-bearing ilium appears first, at the second month, followed by the ischium at the third and pubis at the fourth month of fetal life. At birth the acetabulum is wholly cartilage, and while the ilium is a broad blade of bone the ischium and pubis are no more than tiny bars of bone buried in the cartilage. Growth of these three bones causes them later to approximate each other in a Y-shaped cartilage in the acetabulum. The ischial and pubic rami fuse with each other at about 7 years. Around the whole bone there remain strips of hyaline cartilage as follows; the whole length of the iliac crest, anterior inferior iliac spine, body of pubis at the symphysis, ischial tuberosity and sometimes ischial spine. The Y-shaped cartilage begins to ossify at about 12 years, with the appearance within it of two or three small centres of ossification (*ossa acetabuli*) which enlarge to fuse with each other and the surrounding bones to close the acetabulum soon after puberty (say 15 years). At the same time bony centres appear in the peripheral strips of cartilage. These fuse with the main bone when growth of the whole body ceases (say 25 years).

FEMUR

The **femur**, the bone of the thigh, is now properly called the *os femoris* so that 'femur' alone can revert to its true meaning of 'thigh', but like many changes in anatomical nomenclature it will be many years before the term is widely used. Note first the general features and the *anatomical position* of the bone. Lay it on its back on the table. This shows the forward convexity of the shaft, whose posterior concavity is buttressed by a strong ridge, the *linea aspera*, in its middle third. The head rises off the table, because the neck has an angle of torsion with the shaft of 30°. The neck of the femur passes from the head *backwards* as it slopes down to the shaft. This slope of the neck of the femur is in line with the forward and upward propulsive thrust of normal progression (walking, leaping, etc.) Hold the bone vertically, then place both condyles on the table. This produces an inclination of the shaft which is the true standing position; in life the femoral condyles rest horizontally on the plateau of the tibia. The inclination of the shaft is greater in the female, with her shorter legs and wider pelvis. In the long-legged male the shaft is nearer vertical, and the neck lies more nearly in line with the shaft (say 140°). In the female the neck makes a less obtuse angle with the shaft (say 120°). In the child the position is similar to that of the adult female; it is a matter of the length of the femur and the width of the pelvis.

The **head** of the femur (Figs 3.9 and 3.14), capped with hyaline cartilage, is more than half a sphere. Its medial convexity has a pit, the *fovea*, for the ligament of the head. Anteriorly the articular cartilage extends on the neck. This extension does not articulate with the acetabulum in standing because it is for weight-bearing in the *flexed* hip (try it on the dry bones). The synovial membrane of the hip joint, lining the capsule and covering the retinacular fibres on the neck, is attached to the articular margin of the head.

The **neck** of the femur is an upward extension of the shaft, angled as already noted. The angle is strengthened internally by the *calcar femorale*, a flange of compact bone projecting like a spur into the cancellous bone of the neck and adjoining shaft from the concavity of their junction, well in front of the lesser trochanter. The neck joins the shaft at the greater trochanter above and the lesser trochanter below. Many vascular foramina, directed towards the head, perforate the upper and anterior surfaces of the neck; the largest are for veins, not arteries. Grooves and ridges on the surface indicate the attachment of retinacular fibres, reflected from the attachment of the hip joint capsule to the articular margin of the head. These fibres hold

down the arteries to the head (mostly from the trochanteric anastomosis) and their rupture may result in avascular necrosis of the head of the femur in *intra-capsular* fracture of the neck. Revascularization of the head depends on new vessels crossing the fracture line, not on any within the ligament of the head. The neck joins the greater trochanter in front along a rough ridge, the **intertrochanteric line**. The capsule of the hip joint is attached to the line; the anterior surface of the neck with its adherent retinacular fibres is wholly intra-capsular (Fig. 3.10, p. 153). The back of the neck joins the greater trochanter at a prominent rounded ridge, the **intertrochanteric crest**. Here the capsule of the hip joint is attached to the neck only halfway to the crest; the lower part of the neck alongside the crest is bare bone, over which the tendon of obturator externus plays (Fig. 3.15, p. 161). The intertrochanteric line, as well as receiving the anterior part of the capsule of the hip joint, gives attachment to the iliofemoral ligament (of Bigelow), whose thickest part is received into a low tubercle at the lower end of the line. The pubofemoral ligament is received into the lower surface of the neck alongside the capsular attachment. The ischiofemoral ligament reaches only the zona orbicularis ('ischiocapsular' ligament would be a more accurate name).

The two trochanters are for muscle attachments (Fig. 3.14); each is an epiphysis that ossifies separately from the shaft.

The **greater trochanter** projects up and back from the convexity of the junction of neck and shaft. Its upper border is projected into an intumed apex posteriorly; this carries the upper part of the attachment of gluteus medius. Piriformis is attached here and spreads forward along the upper border deep to gluteus medius. More anteriorly the medial surface of the upper border shows smooth facets for the tricipital tendon of obturator internus and the gemelli. The apex of the trochanter overlies a deep pit, the trochanteric fossa. The bottom of the pit is smooth for the attachment of the obturator externus tendon. The anterior surface of the greater trochanter shows a J-shaped ridge for the gluteus minimus tendon. The lateral surface shows a smooth oblique strip, 1 cm wide, sloping down from the apex of the greater trochanter to the middle of the J-shaped ridge. This is for the tendon of gluteus medius. An expansion from this tendon passes from the apex of the trochanter across to the ilium to blend with the iliofemoral ligament. The prominent convexity of the trochanter below gluteus medius forms the widest part of the hips. It is covered by the beginning of the iliotibial tract, where gluteus maximus is received. This plays freely over a bursa on the bare bone. Posteriorly the apex of the trochanter is continued down as the promi-

nent intertrochanteric crest to the lesser trochanter. Nearly halfway down the crest is an oval eminence, the quadrate tubercle. Quadratus femoris is attached here, but it does not make the tubercle, which is a heaping up of bone at the epiphyseal junction. Quadratus femoris is attached to the tubercle and vertically below it down to a level that bisects the lesser trochanter.

The **lesser trochanter** lies back on the lowest part of the neck. Its rounded surface, facing medially, is smooth for the reception of the psoas major tendon. Iliacus is inserted into the front of the tendon and into the bone below the lesser trochanter.

The **shaft** of the femur is characterized by the **linea aspera** along its middle third posteriorly. This narrow ridge has *medial* and *lateral lips*. Note particularly their manner of formation. The intertrochanteric line slopes across the front of the neck and shaft at their junction, and continues down below the lesser trochanter as a *spiral line* that runs into the medial lip of the linea aspera (Fig. 3.14). The medial lip continues on as the *medial supracondylar line* to the adductor tubercle on the medial condyle. On the back of the shaft below the greater trochanter is a vertical ridge (sometimes a groove) for gluteus maximus. This is the *gluteal tuberosity* or *crest* and it runs down into the lateral lip of the linea aspera, and this lip is continued on as the *lateral supracondylar line* to the lateral epicondyle.

The intertrochanteric line in its lower half gives an aponeurotic origin to vastus medialis, which arises in continuity below this along the spiral line, medial lip of the linea aspera and upper one-third of the medial supracondylar line (the lowest part of this muscle comes from the adductor magnus tendon, not from bone). The medial surface of the femoral shaft is bare bone, over which vastus medialis plays. Vastus lateralis arises in continuity from the upper half of the trochanteric line, the lower part of the J-shaped ridge of gluteus minimus, the gluteal tuberosity, the lateral lip of the linea aspera and the upper two-thirds of the lateral supracondylar line. Vastus intermedius, arising from the front and lateral surfaces of the upper two-thirds of the shaft, extends up to the angle between the trochanteric line and gluteus minimus. Articularis genu arises a quarter of the way up the shaft below the lower limit of vastus intermedius. Thus the three vasti of the extensor compartment enclose almost the whole circumference of the shaft (Fig. 3.18).

Note the attachments in the angle between the gluteal tuberosity and the spiral line, above the linea aspera (Fig. 3.15). Psoas major and iliacus have already been seen. Pectineus is received into this area, behind and below iliacus. Adductor magnus is inserted alongside the gluteal tuberosity with its upper limit, edge to

edge with quadratus femoris, lying at a level that bisects the lesser trochanter. Below this adductor magnus is attached to the middle part of the linea aspera and then to the medial supracondylar line down to the adductor tubercle. There is a gap in the supracondylar attachment, a hand's breadth above the knee, through which the femoral vessels pass into the popliteal fossa, and here the supracondylar line is obliterated. The gluteal tuberosity (or groove) receives the deep half of the lower half of gluteus maximus.

Crowded into the narrow ridge between adductor magnus and vastus lateralis, the short head of biceps femoris arises by a flat sheet of aponeurotic fibres from the whole length of the linea aspera (i.e. middle one-third of shaft of femur), and passes down into the hamstring compartment. Between adductor magnus and vastus medialis are inserted adductor brevis and adductor longus. Adductor brevis is received into the upper one-third of the linea aspera and extends above this behind pectineus. Adductor longus is received as an aponeurotic sheet into the lower two-thirds of the linea aspera. The popliteal surface of the femur between the supracondylar lines is bare. The anterior surface of the lower shaft is likewise bare, with the suprapatellar pouch in contact with periosteum deep to quadriceps tendon for a hand's breadth above the knee joint.

The **lower end** of the femur carries the two **condyles** (Fig. 3.56), separated behind by an intercondylar notch but joined in front by a trochlear surface for the patella. The lateral condyle projects further forward than the medial, thus helping to stabilize the patella (Fig. 3.11). The articular surface of the *trochlea*, covered with hyaline cartilage, extends higher above the knee on the lateral than on the medial condyle. At the

distal surface the lateral condyle is broad and straight, the medial narrow and curved. Both are almost flat anteroposteriorly, but boldly curved on the posterior convexities (Fig. 3.33). They are joined, below the popliteal surface of the shaft, by the *intercondylar ridge* that encloses the *intercondylar fossa*. Just above this ridge the capsule and oblique popliteal ligament of the knee are attached. In the fossa the cruciate ligaments are attached to smooth areas: the *anterior* cruciate ligament far back on the *lateral* condyle alongside the articular margin, the *posterior* far forward on the *medial* condyle alongside the articular margin (Fig. 3.56). The **medial condyle** shows on its convex non-articular medial surface a shallow pit the bottom of which is smooth for the tibial collateral ligament. This is the *epicondyle*. Above it lies the **adductor tubercle** at the lower end of the medial supracondylar line. On the posterior surface, between the adductor tubercle and the articular margin, is a smooth area for the tendinous fibres of the medial head of gastrocnemius. Above this a rough area is raised on the popliteal surface of the shaft by the muscular fibres of gastrocnemius. The **lateral condyle** shows, towards the back of its non-articular lateral surface, a vertical arrangement of three smooth-floored pits (Fig. 3.33). The upper pit is for the tendinous fibres of the lateral head of gastrocnemius. The muscular fibres of the lateral gastrocnemius arise in continuity from the lower half-inch of the lateral supracondylar line, which ends at the pit (Fig. 3.56). Above this plantaris arises from the line (Fig. 3.26). The central pit is at the prominence of the convexity of this surface, the *lateral epicondyle*; the fibular collateral ligament is attached to the pit. The lowermost pit receives the popliteus tendon; a groove behind the pit runs up to the articular margin for lodging the popliteus tendon when the knee is flexed.

The synovial membrane of the knee joint is attached to the articular margin. The capsule is attached to the articular margin except at two places. It is attached posteriorly to the intercondylar ridge, to imprison the cruciate ligaments and it is attached laterally above the pit and groove for the popliteus, to imprison the tendon within the knee joint. Its attachment across the trochlea is a very narrow flange, because here the capsule is widely perforated for communication of the synovial membrane with the suprapatellar bursa.

Surgical approach. The shaft can be exposed from the front between rectus femoris and vastus lateralis by incising vastus intermedius vertically down to the bone. The posterolateral approach is in front of biceps, detaching vastus lateralis from the front of the lateral intermuscular septum and following it down to the shaft.

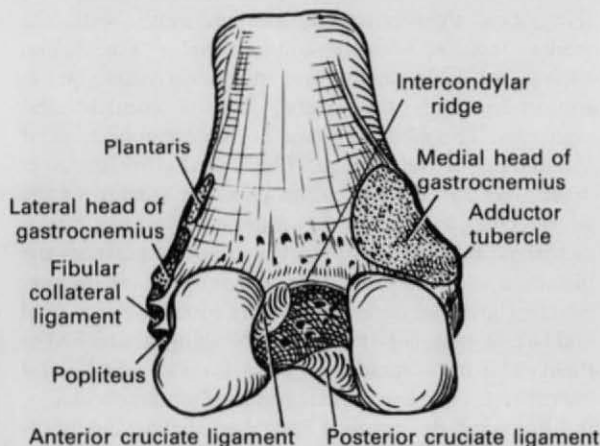


Fig. 3.56 Lower end of the left femur from behind.

Ossification. The whole femur ossifies in cartilage. A centre in the shaft appears at the eighth week of fetal life. A centre for the lower end appears at the end of the ninth fetal month (at birth) and its presence is acceptable medicolegal evidence of maturity. This is the growing end of the bone, and the epiphysis, which bisects the adductor tubercle (Fig. 3.56) unites with the shaft after 20 years. A centre appears in the head at 1 year of age, greater trochanter at 3 and lesser trochanter at 12 years. These upper epiphyses fuse with the shaft at about 18 years of age. Note that the neck of the femur is the upper end of the shaft and ossifies as part of it, not from an epiphysis.

PATELLA

This sesamoid bone in the quadriceps tendon plays on the articular surface of the femur. Its edges form a rounded triangle, its anterior surface is gently convex. The lower border is projected down as an apex to the triangle. The articular surface, covered with hyaline cartilage, extends to the convex upper border but falls short of the lower apical part. Thus upper and lower borders can be identified. The articular surface has a vertical ridge dividing it into narrow medial and broader lateral areas; the bone laid down on a table lies on the broad lateral surface of the facet. So the right patella can easily be distinguished from the left. The narrow medial surface is further divided into two vertical strips (p. 178). The upper border of the bone receives the quadriceps tendon, the medial border receives a flat tendon from the lowest fibres of vastus medialis. The quadriceps tendon sends a few superficial fibres across the front of the bone, grooving its anterior surface, and from each side extensions (patellar retinacula) from the vasti pass down to the patellar ligament and to ridges on the tibia. The patella is attached distally to the tuberosity of the tibia by the ligament. This is attached to the patella across the whole non-articular lower border of the bone. The patellar retinacula extend down from the bone to the side of the patellar ligament before sweeping away to the tibia. The patella is set like a plug in a gap in the anterior capsule of the knee joint. The capsule and synovial membrane are attached to the articular margin. The capsule is very short at its attachment to the upper border, being here widely perforated for the synovial membrane to communicate with the suprapatellar bursa. From the lower articular margin capsule and synovial membrane pass directly across to the margin of the tibial plateau (see below).

The patella remains in constant position relative to the tibia, held there by the patellar ligament. The lower

border of the patella is level with the knee joint (tibial plateau). Stellate fractures may show no displacement of fragments if the overlying quadriceps expansions and retinacula remain intact. The bone can be removed with surprisingly little disability.

Ossification. The bone forms in hyaline cartilage by a centre that appears at 3 years; there is sometimes more than one centre. Ossification is complete soon after puberty.

TIBIA

The **tibia**, the larger and medial bone of the (lower) leg, has a large upper end and a smaller lower end (Fig. 3.60). The shaft is vertical in the standing position; the femur *inclines* up from the head of the tibia outwards to the acetabulum. Much of the bone is subcutaneous and so is easily palpable.

The **upper end** is widely expanded, and there is a prominent tuberosity projecting anteriorly from its lower part. The surface bone is of the very thin compact type which is fragile particularly around the margins of the upper surface or plateau. Try to secure a perfect specimen for study. Before studying the features of the upper end it is well to note the line of the epiphysis, to see whether structures are attached to it or to the shaft. The *epiphyseal line* cuts across the lower margin of each condyle at the back, and in front dips down to include the upper smooth part of the tuberosity (Fig. 3.57). The chief points that will be noted are that the fibular facet and the attachments of semimembranosus and the patellar ligament are on the epiphysis.

The **superior articular surface** or plateau shows a pair of gently concave condylar articular areas, for articulation with the menisci and the condyles of the femur (Fig. 3.58). The surface on the medial condyle is oval (long axis anteroposterior) in conformity with the medial femoral condyle and meniscus. The lateral surface is a little smaller and more nearly circular, in conformity with the lateral femoral condyle and meniscus. The medial surface does not extend beyond the margin of the plateau. The lateral surface curves down over the margin to the posterior surface of the lateral condyle (this is for movement of the lateral meniscus, p. 176). Between the condylar surfaces the plateau is elevated into the **intercondylar eminence**, which is grooved anteroposteriorly to form the medial and lateral *intercondylar tubercles*. Nothing is attached to them. The non-articular areas in front of and behind the tubercles show well-marked facets for attachment of the horns of the menisci and the cruciate ligaments (Fig. 3.29). In front of the tubercles is a large smooth area for attachment of the anterior cruciate ligament.



Fig. 3.57 Epiphyseal lines at the upper end of the left tibia and fibula (aged 18 years) from the front. The epiphysis includes the attachment of the patellar ligament and, towards the back, the facet for the superior tibiofibular joint.

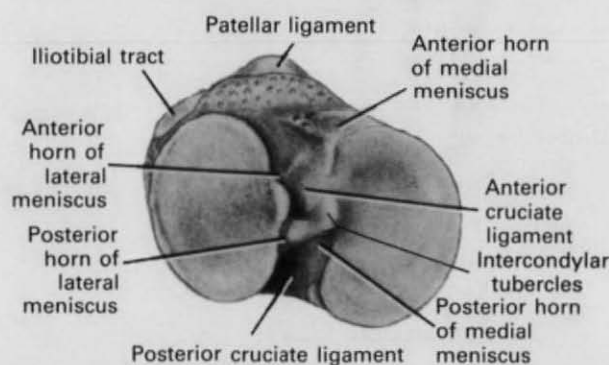


Fig. 3.58 Superior surface of the left tibia, with ligamentous attachments indicated.

The lateral margin of this area receives the anterior horn of the lateral meniscus, just in front of the lateral intercondylar tubercle. Further forward, at the margin of the tibial plateau, is a round smooth facet for the anterior horn of the medial meniscus. Behind the tubercles is a smooth area sloping down to an oblique ridge between the posterior convexities of the condyles. The

posterior cruciate ligament is attached to the ridge and to the smooth slope above it. The posterior horn of the medial meniscus is attached to a deep slit behind the medial intercondylar tubercle. The posterior horn of the lateral meniscus is attached, in front of the posterior cruciate ligament, just behind the lateral intercondylar tubercle.

The capsule of the knee joint is attached to the circumference of the tibial plateau except in two places. Where the tendon of popliteus crosses the margin of the tibia the capsule extends down to the head of the fibula. Between the condyles posteriorly the capsule is attached not to the margin of the plateau but to the ridge below the groove for the posterior cruciate ligament (Fig. 3.59). The synovial membrane is attached to the edge of each articular surface, following the condylar margins alongside the spine to be draped over the attachment of the anterior cruciate ligament.

The **condyles** lean back over the popliteal surface of the shaft (Fig. 3.59). The back of the **medial condyle** is deeply grooved for the semimembranosus insertion (Fig. 3.60); this groove extends around the medial contour of the bone, to receive the expansion of the tendon beneath the tibial collateral ligament. The ligament is not attached to the condyle, but to the shaft lower down. The lateral condyle carries the **facet** for the head of the fibula (see p. 189). The capsule and synovial membrane of this tibiofibular joint are attached to the articular margin. Just above this facet the lateral condyle may show a groove for the popliteus

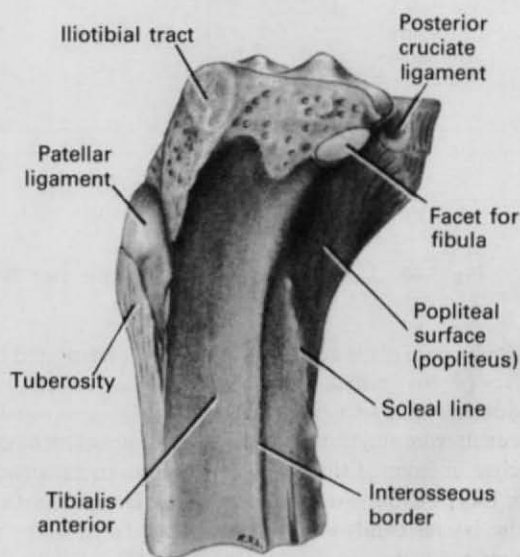


Fig. 3.59 Upper end of the left tibia, from the lateral side

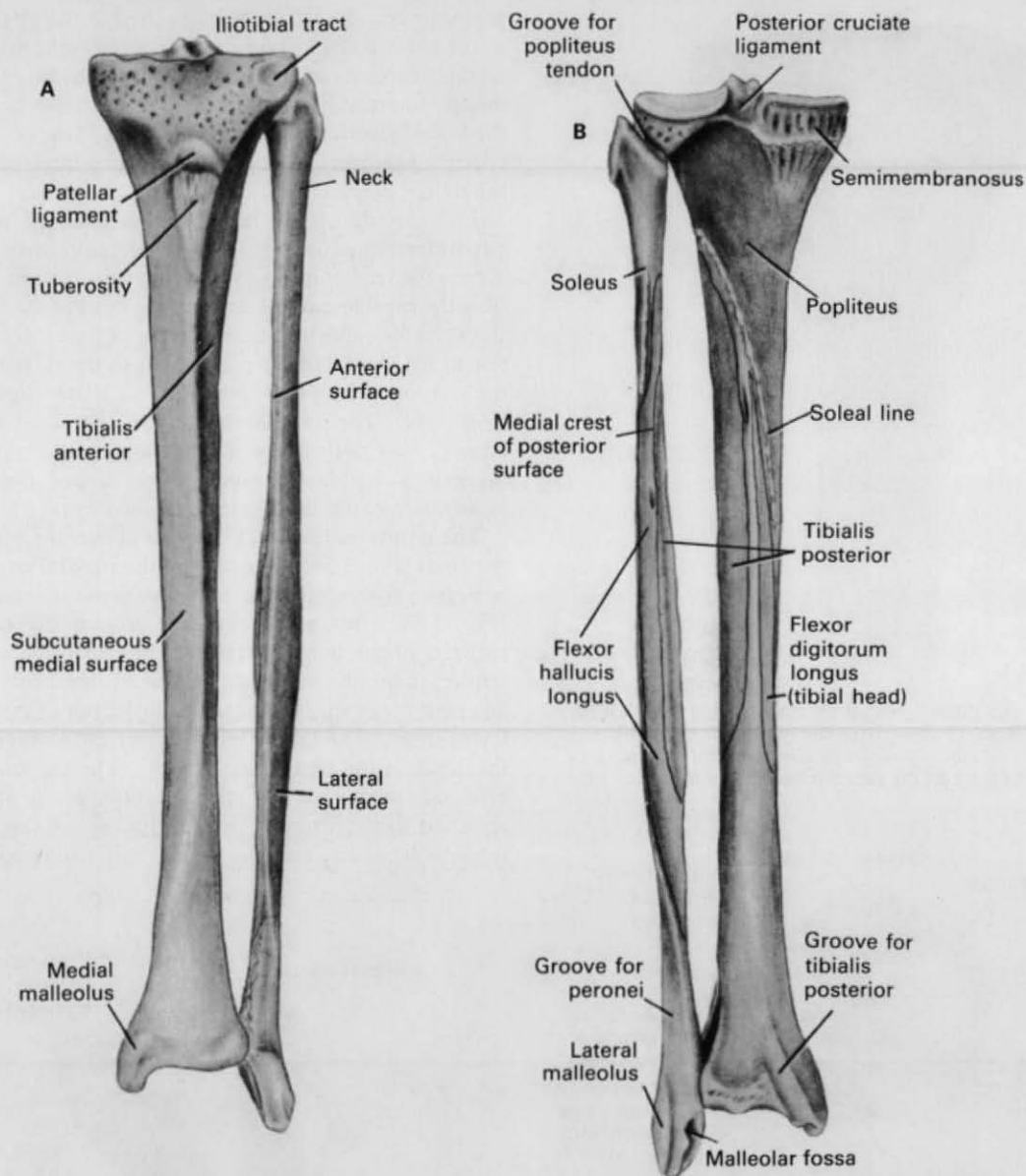


Fig. 3.60 Left tibia and fibula, **A** from the front, **B** from behind.

tendon, which plays across the bone here, lubricated by the popliteus bursa. Small upward extensions of peroneus longus and extensor digitorum longus usually encroach from the fibula on the lateral convexity of the condyle in front of the fibular facet, and an expansion from biceps femoris overlies them. The anterior surface of the lateral condyle shows a smooth facet, 1 cm in diameter, for the iliotibial tract (Fig. 3.33). Below it a ridge slopes down to the tuberosity. A similar ridge

extends down from the medial condyle. Expansions from vastus lateralis and medialis, known as patellar retinacula, are attached to these ridges. The **tuberosity** shows a smooth oval prominence set obliquely; it receives the quadriceps insertion via the patellar ligament. The rough triangular area on the lower part of the tuberosity is subcutaneous and covered by the subcutaneous infrapatellar bursa. The space between the capsular attachment and the patellar retinacula

contains soft extracapsular fat that adapts its shape to the changing contours of the femoral condyles in flexion-extension of the knee. Deep to the patellar ligament lies an infrapatellar bursa (Fig. 3.28).

The **shaft** of the tibia is triangular in section. Its **anterior** and **posterior borders**, with the medial surface between them, are subcutaneous. The subcutaneous surface receives the tendons of sartorius, gracilis and semitendinosus at its upper end (p. 185), and behind these the tibial collateral ligament is attached. The surface is continued at its lower end into the medial malleolus. The anterior border is sharp above, where it shows a medial convexity imprinted by tibialis anterior. This border becomes blunt below, where it continues into the anterior border of the medial malleolus. The blunt posterior border runs down into the posterior border of the medial malleolus.

On its fibular side the tibia shows a sharp **interosseous border** which, over 4 cm ($1\frac{1}{2}$ in) from the lower end, splits into two. The interosseous border gives attachment to the interosseous membrane, whose oblique fibres slope down to the fibula. In front of the interosseous border is the extensor surface of the shaft. This surface runs from the upper end below the lateral condyle to spiral over the front of the lower end of the tibia. Tibialis anterior arises from the upper two-thirds or less of this surface. Below the muscle the extensor surface of the tibia is bare. It is crossed by the tibialis anterior and extensor hallucis longus tendons. The flexor surface of the shaft lies behind the interosseous border. Its upper part is distinguished by the **soleal line**, which runs down obliquely from just below the tibiofibular joint across this surface to meet the posterior border one-third of the way down. Popliteus arises from the popliteal surface of the tibia above the soleal line; the popliteus fascia, a downward extension from semimembranosus tendon, is attached to the line. The upper end of the soleal line often shows a tubercle for attachment of a fibrous band that passes to the head of the fibula, bridging the posterior tibial neurovascular bundle. From this band, the soleal line, and the *middle third of the posterior border* the soleus arises in continuity. Below the soleal line the flexor surface shows a vertical ridge. Tibialis posterior arises between this ridge and the interosseous border (it crosses the interosseous membrane to arise also from the fibula). Medial to the ridge, between it and the posterior border, flexor digitorum longus arises. The upper part of this surface is perforated by a large nutrient foramen directed downwards. The lower part of this surface is bare bone, crossed by tibialis posterior and the overlying flexor digitorum longus.

The **lower end** of the tibia is rectangular in section.

Medially the surface is subcutaneous, with the great saphenous vein and nerve crossing above the **medial malleolus** (Fig. 3.2). Anteriorly the bare bone is crossed by the tendons of tibialis anterior and extensor hallucis longus and the anterior tibial neurovascular bundle and extensor digitorum longus (Fig. 3.36). There may be a facet (the 'squatting' facet) just above the articular margin, for articulation with the neck of the talus in full dorsiflexion of the ankle joint. Laterally the surface is triangular between the ridges that diverge from the lower end of the interosseous border; this triangular area gives attachment to the strong interosseous tibiofibular ligament. The lower part of this surface may articulate with the fibula as a synovial upward continuation of the ankle joint. Posteriorly there is a groove behind the medial malleolus, made deeper in life by thickening of periosteum at its margins. The tendon of tibialis posterior, in its synovial sheath, is lodged here, bridged by a band of fibrous tissue (Fig. 3.39). Alongside it the tendon of flexor digitorum longus crosses the bone, while on the fibular side the posterior surface has the lower end of the fleshy belly of flexor hallucis longus in contact with bare bone. The distal surface shows a saddle-shaped facet for the talus, the articular surface extending to line the medial malleolus. The capsule and synovial membrane of the ankle joint are attached to these articular margins (and to the posterior tibiofibular ligament). The distal surface of the medial malleolus shows a smooth area for the deep lamina of the deltoid ligament, and the superficial part of the ligament is attached more superficially (the deltoid ligament is as thick as the bone of the malleolus). The upper limb of the inferior extensor retinaculum is attached superficially, to the front of the malleolus.

The fascia lata of the thigh is attached to the ridges running down to the tuberosity, along with the patellar retinacula. The deep fascia of the calf is attached to the anterior and posterior borders of the shaft, down to the medial malleolus. It is thickened at the lower end of the extensor compartment as the superior extensor retinaculum (p. 186), and from the back of the medial malleolus a band passes to the calcaneus as the flexor retinaculum.

Surgical approach. The front of the shaft is exposed by incision over tibialis anterior and detachment of the muscle from the bone. The incision is not made over the bone itself since healing over the muscle is better. The posteromedial approach is along the posterior border of the bone, detaching soleus and flexor digitorum longus. Damaged tissue (which would not heal well) over the subcutaneous surface of the bone may necessitate a posterolateral approach, which begins by opening up the interval between peroneus

longus and soleus, using the common peroneal nerve as the guide to the interval. Then flexor hallucis longus is stripped off the back of the fibula, and tibialis posterior from the fibula, interosseous membrane and the tibia. By keeping close to the bone when stripping the fibula, the peroneal vessels are displaced with the muscles.

Ossification. The shaft ossifies in cartilage from a primary centre that appears in the 8th week of fetal life. The upper epiphysis (the growing end) shows a centre immediately after birth. This joins the shaft at 20 years along the epiphyseal line already noted. A secondary centre for the tuberosity may appear about puberty. The lower epiphysis ossifies at the second year and joins the shaft at 18 years. The epiphyseal line passes a centimetre above the distal end of the shaft and includes the medial malleolus; it is extracapsular.

FIBULA

The slender shaft of the **fibula**, the lateral bone of the leg, expands above into a *quadrilateral head* and below into a *flattened malleolus* (Fig. 3.60). Thus can upper and lower ends be identified. The vertical articular surface at the lower end has a pit, the malleolar fossa, behind it. Looking at these features enables the left and right fibulae to be distinguished: the fossa is to the left in the left fibula, to the right in the right fibula (Fig. 3.61).

The bone is difficult to study, and should be placed against its companion tibia to appreciate properly its surfaces and attachments.

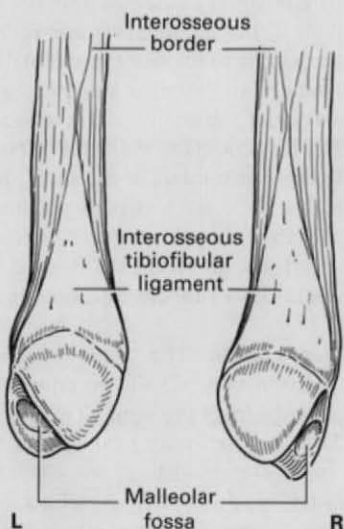


Fig. 3.61 Lower ends of the left and right fibulas, distinguished by the position of the malleolar fossa behind the triangular articular area.

The **head** of the fibula carries an oval or round facet set obliquely on its upper surface; this articulates with a reciprocal facet on the upper epiphysis of the tibia. The capsule and synovial membrane of the superior tibiofibular joint are attached to the articular margin. The back of the head is projected upwards as the *styloid process*. The arcuate ligament is attached to it (p. 181). The fibular collateral ligament is attached in front of the styloid process, with biceps tendon still further forward, on the upper surface (Fig. 3.29). From the styloid process a groove for the popliteus tendon slopes down behind the articular surface.

The **shaft** has three surfaces, anterior, lateral and posterior, corresponding to the extensor, peroneal and flexor compartments of the leg. The *lateral (peroneal) surface* is smooth and easy to identify. The groove behind the lateral malleolus spirals up behind the triangular subcutaneous surface of the lower end to the lateral surface of the shaft and so up to the head. Peroneus brevis arises from the lower two-thirds of this surface and its tendon passes down to groove the back of the malleolus. Peroneus longus arises from the upper two-thirds (behind brevis where they overlap) and its tendon passes down behind that of peroneus brevis. The common peroneal nerve enters peroneus longus at the **neck** of the bone, the part of the shaft adjoining the head; the nerve can be rolled against the bone here, where it may be damaged by a plaster cast or tight bandaging. It also divides here into its superficial and deep branches. The superficial peroneal nerve, supplying peroneus longus and brevis, passes down to emerge between them. The deep peroneal nerve pierces the anterior peroneal septum to reach the extensor compartment of the leg. These nerves, very close to the bone, are not in actual contact with it, being cushioned by a few deep fibres of peroneus longus. The ridges that border the peroneal surface give attachment to the anterior and posterior septa that enclose the peroneal muscles.

Identify the interosseous border as follows. Above the malleolar facet is a somewhat rough triangular surface for the interosseous tibiofibular ligament (Fig. 3.61). From the apex of this triangular area a short ridge passes upwards and forks into two; the posterior one is the *interosseous border* and the anterior is the *anterior border*. The *anterior surface* is now seen to be extremely narrow, especially at its upper end, where in some bones the anterior and interosseous borders fuse. From the upper three-fourths of this narrow strip extensor digitorum longus takes origin, and here the deep peroneal nerve touches the bone beneath the muscle. In continuity with this muscle peroneus tertius arises from the lower third, where the anterior surface broadens

somewhat. Deep to this (i.e. towards the interosseous border) extensor hallucis longus arises from the middle two-fourths of the fibula and the adjacent interosseous membrane.

The *posterior (flexor) surface*, between the interosseous and posterior borders, is much wider. The middle third of this surface shows a vertical ridge, the *medial crest*, which runs down towards the interosseous border and up towards the neck. It divides this part of the posterior surface into medial and lateral parts. To the medial part, between the medial crest and the interosseous border, tibialis posterior is attached (Fig. 3.60B; it crosses the interosseous membrane to a similar area on the tibia, lateral to the vertical line). The medial crest itself gives attachment to what is usually described as a deep intermuscular septum but which may be considered the aponeurotic fibular origin of flexor digitorum longus (Fig. 3.39). The lateral part of the posterior surface, between the medial crest and the posterior border, is for flexor hallucis longus. Below the medial crest (i.e. below the origin of tibialis posterior) flexor hallucis longus continues to arise from the whole posterior surface and from the interosseous membrane as far as the inferior tibiofibular joint. Here a spiral twist of the posterior surface matches the spiral twist of the peroneal surface. The upper part of the flexor surface, varying from a quarter to one-third, gives origin to soleus; a roughened 'soleal line' shows on many bones (Fig. 3.60).

The **lateral malleolus** projects further distally than the medial (tibial) malleolus. Its medial surface has a triangular articular surface for the talus. Capsule and synovial membrane of the ankle joint are attached to the articular margin except posteriorly, where they are carried on the posterior tibiofibular ligament. The **malleolar fossa** behind this surface is perforated by foramina. It gives attachment to two ligaments that diverge to the tibia and the talus: the posterior tibiofibular ligament, which articulates with the talus and carries the ankle-joint capsule, and the posterior talofibular ligament. The triangular subcutaneous area has a rounded lower margin with a smooth area in front for the anterior talofibular ligament and a similar area just in front of the apex for the calcaneofibular ligament (Fig. 3.46). Between the subcutaneous area and the malleolar fossa is a smooth groove for the tendon of peroneus brevis (the longus tendon lies on it and does not touch the fibula). The two tendons are in a common synovial sheath, and bridged by the superior peroneal retinaculum, a band of fibres passing from the tip of the malleolus to the calcaneus. Injuries at the ankle, e.g. Pott's fracture of the tibial malleolus, may be associated with fractures of the *upper* part of the shaft of the fibula.

Surgical approach. The fibula can be exposed from the lateral side, along the interval between peroneus longus and soleus, using the common peroneal nerve at the upper end as the guide to the interval.

Ossification. The fibula ossifies in cartilage by a centre in the shaft which appears in the eighth week. There is an epiphysis at each extremity. The head, the growing end, is exceptional in ossifying later (fourth year) than the lower end (second year). The upper epiphysis fuses with the shaft at 20 years, the lower before this (say 18 years).

FOOT

The principal joints of the tarsal bones have already been studied (pp. 203–209), and the movements of inversion and eversion should be well understood before osteological details of individual bones are studied. The tarsus is built from seven bones. It articulates by the talus at the ankle joint, and it also provides the mobility of inversion–eversion by its midtarsal and subtalar joints. Only one of the seven bones, the calcaneus, rests on the ground. The metatarsus articulates with the tarsus, and the metatarsal heads, especially the first and fifth, rest on the ground. The toes lie free to move in front of the metatarsal heads, which are weight-bearing, the first taking more weight than the others.

CALCANEUS

The **calcaneus**, the heel bone, is the largest of the tarsal bones and the first to ossify (p. 234). It articulates with the talus above and the cuboid in front. It is a rectangular block of bone, characterized by the sustentaculum tali, a shelf that projects from the upper border of its medial surface (Fig. 3.62).

The **upper surface** carries articular surfaces on its anterior half. The sustentaculum tali and the anterior part of the body show a common articular surface, elongated and concave; this may be separated into two halves, but even so they occupy the one joint cavity with the head of the talus. Study of the talocalcaneonavicular joint (p. 205) will make clear the attachments to the margins of this articular surface. The capsule and synovial membrane of the talocalcaneonavicular joint are attached to only the posterolateral margin (Fig. 3.49). The anteromedial margin is in the joint space, with the spring ligament attached to the margin of the sustentacular surface and the synovial membrane over the fat pad attached to the articular margin on the body of the calcaneus. Behind the sustentacular facet an oblique groove (the floor of the tarsal sinus, p. 207) passes laterally and forwards to a wide non-articular

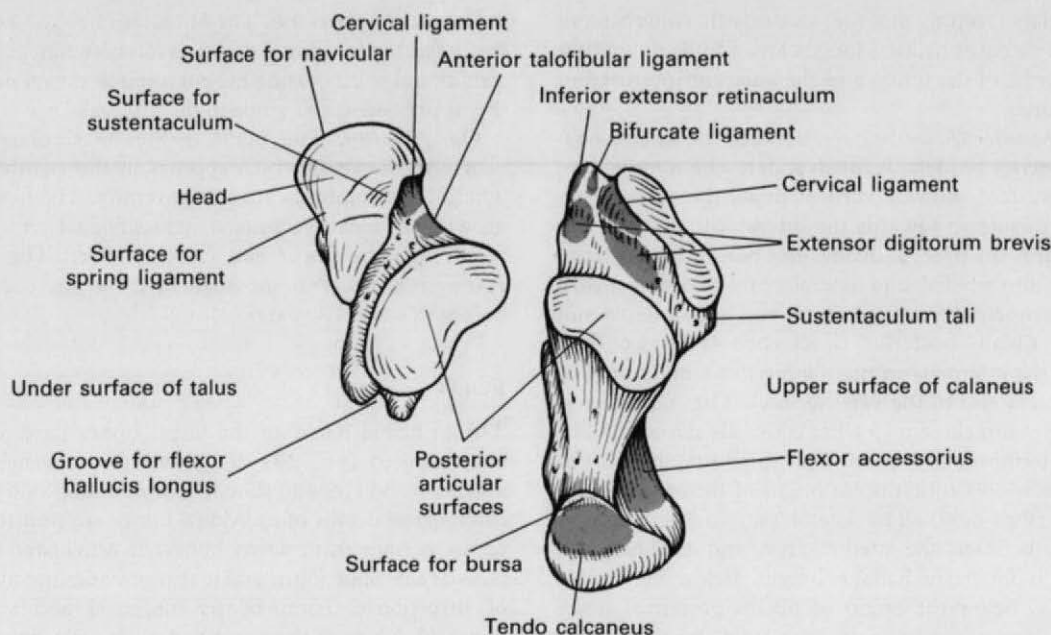


Fig. 3.62 Left talus and calcaneus, as seen when the talus is lifted off the calcaneus and turned over to show its under surface.

area which floors in the open lateral part of the sinus. The groove gives attachment to the talocalcaneal interosseous ligaments. In the sinus a smooth round facet alongside the lateral margin is for the cervical ligament (Fig. 3.62). The bifurcate ligament is attached to the anterior margin of the calcaneus. Behind this is the origin of *extensor digitorum brevis* and, at the lateral margin of the sinus, the inferior extensor retinaculum is attached (Fig. 3.49). Behind the tarsal sinus is a convex articular surface, oval-shaped, its long axis parallel with the groove. Here the talus articulates by a separate joint (talocalcaneal); the capsule and synovial membrane are attached to the articular margin. These two joint surfaces on the anterior half of the calcaneus together constitute the inferior surface of the 'subtalar' joint (p. 205), where inversion and eversion take place. The non-articular posterior half of the upper surface is saddle-shaped (with the rider facing forwards).

The **posterior surface** has a smooth upper part for the *tendo calcaneus*. Its lower part, convex, is grooved longitudinally for attachment of the posterior fibres of the plantar aponeurosis, which sweep back from the under surface. The extreme upper part, below an upturned lip, is bare for a bursa that lies here deep to the *tendo calcaneus*.

The **inferior surface** shows two tubercles, a large medial and a smaller lateral, at its posterior end which,

in official terminology, are called processes and collectively form the tuberosity of the calcaneus (Fig. 3.64). These form the weight-bearing part of the bone. The medial tubercle gives origin to *abductor hallucis*, *flexor digitorum brevis* and part of *abductor digiti minimi*, and the lateral tubercle to the rest of *abductor digiti minimi*. The lateral head of *flexor accessorius* arises from the lateral tubercle deep to these muscles. Superficial to these muscles the plantar aponeurosis is attached, some fibres sweeping up to grooves on the back of the bone as noted above. In front of the tubercles the narrow inferior surface is grooved by the attachment of the long plantar ligament. This surface tapers to the smooth anterior tubercle of the calcaneus, often called the anterior tuberosity, with a fossa in front of it. The fossa fits a similar fossa behind the ridge on the cuboid; a fingertip lies comfortably here when the two bones are articulated. The fossa is filled by the short plantar ligament, which is attached to the anterior tubercle.

The **anterior surface** carries the articular surface for the cuboid, an undulating surface that is slightly lipped above and bevelled below.

The **lateral surface** carries an oblique ridge below and behind the tarsal sinus (Fig. 3.46). This is the *peroneal trochlea*, from which the inferior peroneal retinaculum bridges the sheathed tendons of *peroneus*

brevis in the groove above and peroneus longus in the groove below the trochlea (Fig. 3.37). Much further back the calcaneofibular ligament of the ankle joint slants back to its attachment; this generally leaves no distinguishing mark on the bone. The rest of the lateral surface is bare bone, perforated by numerous blood vessels.

The **medial surface** is concave (Fig. 3.62). The fleshy medial head of flexor accessorius occupies the whole of this area, down to the medial tubercle. Above the concavity the **sustentaculum tali** projects; its under surface is deeply grooved by the tendon of flexor hallucis longus in its sheath. The rounded medial border of the sustentaculum gives attachment across its whole thickness to the spring ligament in front and the superficial part of the deltoid ligament behind (Fig. 3.48). The tendon of flexor digitorum longus lies superficial to the sustentaculum.

The peroneal trochlea is palpable, and the weight-bearing medial and lateral tubercles can be felt through the thickness of the heelpad. The sustentaculum, lying inferior to the medial malleolus, is more difficult to feel because its border is overlaid by the tendon of flexor digitorum longus.

TALUS

The **talus** carries the whole body weight. It lies on the weight-bearing calcaneus, below the tibia, and communicates thrust from the one to the other. The bone possesses a body which is prolonged forward into a neck and a rounded head.

The upper surface of the **body** carries an articular area, the **trochlea**, which is convex from front to back but with a shallow central groove (i.e. concave from

side to side) (Fig. 3.47). The trochlea is usually broad in front and narrow behind, its lateral border curving backwards and medially. The posterior end of this lateral border is blunt, or bevelled, by the posterior tibiofibular ligament, which here comes into contact with the margin of the trochlea (Fig. 3.45), particularly in dorsiflexion of the ankle joint. The trochlear surface is continued down over each side of the body for articulation with the stabilizing malleoli. On the medial surface the articular area is comma-shaped, with the broad end anterior (Fig. 3.63); this area articulates with the malleolus of the tibia. In the concavity of the comma curve there are many vascular foramina. Behind these the deep lamina of the deltoid ligament is attached to a smooth area. On the lateral surface the articular area is much bigger, covering almost the whole surface (Fig. 3.63). Triangular in outline, it is concave from above down and usually convex from front to back. This surface articulates with the fibular malleolus.

Behind the trochlea the talus is projected into a **posterior process** which is deeply grooved by the tendon of flexor hallucis longus (Fig. 3.63) (the groove lies in line with the groove on the under surface of the sustentaculum tali). The posterior process projects as a pair of tubercles, one on either side of the flexor hallucis longus groove. The **lateral tubercle** is the most posterior part of the talus. This may form a separate ossicle, the **os trigonum** (morphologically the os intermediale, the counterpart of the lunate bone of the wrist, p. 237). The lateral tubercle gives attachment to the posterior talofibular ligament, and this ligament lies in a groove below the articular margin almost to the apex of the fibular surface. The less prominent **medial tubercle** is blunt and rounded; it gives attachment to the posterior fibres of the deltoid ligament.

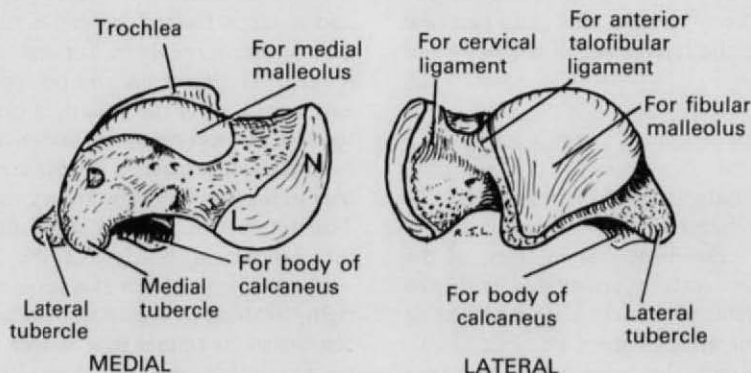


Fig. 3.63 Left talus from the medial and lateral sides. D: area of attachment of deep part of deltoid ligament. L: surface for articulation with anterior part of deltoid ligament. N: area for navicular.

The capsule of the ankle joint is attached to the articular margin except in front, where its attachment encroaches forward on the neck of the talus. The synovial membrane is attached to the articular margin.

The **inferior surface** of the body of the talus (Fig. 3.62) has a large oblique facet, concave for articulation with the calcaneus. In front of this the **neck** is grooved to fit over the corresponding groove on the calcaneus to make the tarsal sinus. The groove gives attachment to the interosseous talocalcaneal ligament. Laterally the neck carries a smooth round facet for attachment of the cervical ligament, and behind this the anterior talofibular ligament is attached. The neck of the talus is very short, and is directed forwards and medially.

The rounded **head** of the talus is capped by a large articular surface facing forwards and downwards. Anteriorly the surface is convex for articulation with the navicular. Inferiorly it is flattened for articulation with the sustentaculum tali and the body of the calcaneus; a low ridge commonly separates this calcaneal area into two flat facets. The navicular convexity and the calcaneal flattening are separated from each other by a triangular convexity (base of the triangle at the neck of the talus) for the spring ligament and the deltoid ligament, according to the position of inversion or eversion of the foot. The convex navicular surface articulates laterally with the bifurcate ligament (Fig. 3.49). The head of the talus is the ball of the ball and socket talocalcaneonavicular joint, whose capsule and synovial membrane are attached around the neck of the talus to the articular margin of the head.

The talus has a good anastomotic blood supply within the bone from various sources—dorsalis pedis branches into the head and neck, posterior tibial into the medial side of the body and the sinus, and peroneal (fibular) branches into the lateral side of the body and the sinus.

CUBOID BONE

This bone is rather wedge-shaped, narrowest at the lateral margin and broadest medially where it articulates with the lateral cuneiform. Set in front of the calcaneus, its anterior surface articulates with the fourth and fifth metatarsal bones, thus completing the lateral longitudinal arch of the foot (Fig. 3.64). Medially it articulates with the lateral cuneiform, and sometimes with the navicular. Its calcaneal surface is undulating, slightly bevelled above and laterally and slightly lipped below and medially. Its anterior surface,

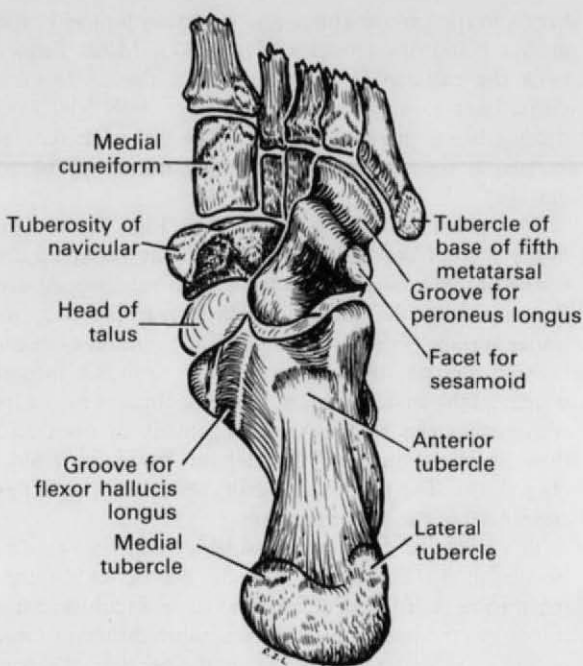


Fig. 3.64 Left tarsal bones from below.

concave from above down, is slightly convex from side to side. A low vertical ridge separates two facets, rectangular for the base of the fourth metatarsal and triangular for the base of the fifth. The medial surface shows an oval facet, high against its upper border, for the lateral cuneiform; the posterior end of this facet is occasionally prolonged for 2 or 3 mm for a tiny synovial joint with the navicular. The dorsal surface of the bone is bare, the margins here giving attachment to the joint capsules and interosseous ligaments. The short lateral border is projected into a small anterior and a large faceted posterior tubercle, with a deep groove between them for the tendon of peroneus longus. The facet on the posterior tubercle, smooth and round, is for the sesamoid cartilage or bone in the tendon. Inspection of the under surface shows that the tubercles on the lateral border are actually the extremities of a pair of oblique ridges on the inferior surface. The anterior of these is inconspicuous, being merely the prominent border of the metatarsal articular surface. The posterior is a prominent ridge in its own right, bridged by the long plantar ligament to make a fibro-osseous tunnel that lodges the peroneus longus tendon and its synovial sheath. Behind the ridge is a deep hollow to which is attached the short plantar ligament and part of the origin of flexor hallucis brevis.

NAVICULAR BONE

In so far as it is concavoconvex, this bone may be said to be boat-shaped, with a prominent medial tuberosity representing the prow of the boat (Fig. 3.47). A proximal concave articular surface fits the convexity of the head of the talus. Here the upper and lateral margins give attachment to the capsule and synovial membrane of the talocalcaneonavicular joint. The inferior margin gives attachment to the spring ligament medially, to the bifurcate ligament laterally, and to the synovial membrane over the fat pad between these two (Fig. 3.49). The distal convex articular surface is divided by a V-shaped ridge into three triangles, the medial one base down, the other two apex down. These articulate with the three cuneiform bones. The lateral facet may extend from the distal to the lateral surface of the navicular for articulation with the cuboid. The joint between the navicular and the three cuneiforms is a single synovial cavity that is continuous along either side of the intermediate cuneiform with the cavity along the bases of the second to the fifth metatarsals.

The **tuberosity** is palpable in all feet and visible in most. Its smooth convexity gives insertion to *tibialis posterior* and from this bone 'expansions' diverge widely, to the cuboid ridge, to the cuneiforms and the metatarsal bases. Many of these bands are ligaments, and not really fibres from the tendon itself. Below the tuberosity is a smooth area, as wide as the thickness of the sustentaculum tali, for attachment of the spring ligament, which is of corresponding thickness.

CUNEIFORM BONES

The three cuneiform bones, true to their name, are all wedge-shaped. The medial is the largest and lies edge upwards. The intermediate is the smallest and, with the lateral, lies edge downwards in the transverse arch (Figs 3.47 and 3.64). All three articulate posteriorly with the navicular, and anteriorly each articulates with its metatarsal bone, thus completing the medial longitudinal arch (p. 210).

The **medial cuneiform** has a *medial surface* which shows a smooth round facet at its anterior inferior angle. *Tibialis anterior* is inserted into the facet (and into a smaller facet on the adjoining base of the first metatarsal). A small area at the upper limit of the *lateral surface* articulates with the intermediate cuneiform and the base of the second metatarsal. Below this articular area, in the sole of the foot, the lateral surface is largely occupied by the attachment of strong interosseous ligaments. At the anterior inferior angle is a low tubercle opposite a large smooth fossa on the adjoining base of

the first metatarsal. *Peroneus longus* is inserted into the tubercle and into the metatarsal base. The *anterior surface*, wholly articular, is kidney-shaped. It forms a separate synovial joint with the base of the first metatarsal bone. Slight gliding occurs here with up and down movements of the medial longitudinal arch. Capsule and synovial membrane are attached to the articular margins. The *posterior surface* is occupied by a smaller pear-shaped facet for the navicular.

The **intermediate cuneiform** articulates by small synovial joints with the medial and lateral cuneiforms, and is bound to them by strong interosseous ligaments. It lies base upwards, and is the shortest of the three, so the base of the second metatarsal is mortised between the medial and lateral cuneiforms.

The **lateral cuneiform**, base up, articulates laterally with the cuboid, to which it is bound by strong ligaments. It projects further distally than the intermediate cuneiform, thus articulating with the base of the second metatarsal (Fig. 3.47). The proximal part of the undersurface forms part of the origin of *flexor hallucis brevis*.

Note that the synovial joints between the three cuneiforms and between the lateral cuneiform and cuboid all lie at the upper limits of the adjacent surfaces. The broad lower parts of these surfaces give strong fixation to plantar interosseous ligaments that bind the bones firmly together in the transverse arch of the foot.

Each cuneiform articulates with the base of its own metatarsal bone. The first forms a *separate synovial cavity*. The other four metatarsal bases, articulating with intermediate and lateral cuneiforms and the cuboid, and with each other, share a common joint space. This space extends back alongside the intermediate cuneiform into the joint between the cuneiforms and the navicular.

METATARSAL BONES

The **first metatarsal** is a thick bone which transmits thrust in propulsion of the body. Proximally a kidney-shaped facet on the base articulates with the medial cuneiform by a synovial joint. On the lateral side of the base a small facet against the upper pole of the kidney articulates with the second metatarsal base, and a smooth fossa opposite the lower pole of the kidney receives *peroneus longus* tendon. The shaft is flattened dorsally, but inferiorly it is braced by a ridge that arches up between base and head. The head has a distal articular surface that extends convexly on the dorsal surface and extends still more on the plantar surface, where it shows a pair of parallel deep grooves for the sesamoid

bones. These bones receive short muscles (abductor, flexor, adductor) whose tendons pass to the proximal phalanx; the sesamoid bones are themselves attached to the capsule of the metatarsophalangeal joint.

The **second to fifth metatarsals** have slender shafts, and there is no flat dorsal triangular area as on the metacarpals. The mortise for the base of the second has already been noted. The metatarsal shafts give attachment to the interosseous muscles. Plantar interossei arise from the shaft of their own bone (third, fourth and fifth metatarsals) and adduct their toes towards the second toe. Dorsal interossei arise from both bones of their space, and abduct the second, third and fourth toes away from the line of the second metatarsal bone (Fig. 3.44). The metatarsal heads are united by a series of deep transverse ligaments that bind them together. The plantar aspects of the bases of the second, third and fourth metatarsals afford origins for the oblique head of adductor hallucis.

The base of the fifth metatarsal is prominent, lateral to the joint with the cuboid, as a proximally directed *tuberosity* which receives the tendon of peroneus brevis (Fig. 3.64). The dorsal surface of the base, next to the base of the fourth, receives peroneus tertius, whose tendon extends along the top of the shaft for a variable distance, even up to the neck of the bone (Fig. 3.37). The plantar aspect of the base gives origin to flexor digiti minimi brevis.

PHALANGES

As in the hand, there are two for the preaxial digit and three each for the others. Each metatarsophalangeal joint is greatly strengthened by a thick pad of fibrocartilage (plantar ligament) on its plantar surface. The pad serves as a connecting ligament and at the same time is the plantar part of the capsule of the synovial joint. Sesamoid fibrocartilages occur normally in pairs in the second and fifth pads and eventually ossify in a very variable pattern. Collateral ligaments, as in the hand, reinforce the sides of the joints. A similar arrangement exists in the interphalangeal joints.

Each phalanx of the big toe receives a separate extensor tendon into its base. The distal phalanx receives extensor hallucis longus, the proximal extensor hallucis brevis (part of extensor digitorum brevis). There are similar flexor attachments on the plantar surface; flexor hallucis longus is inserted into the base of the distal phalanx, and flexor hallucis brevis, via the two sesamoids, into the sides of the base of the proximal phalanx. The other four toes receive tendons as do the fingers. On the plantar surface flexor digitorum brevis splits into a chiasma for insertion into

the intermediate phalanx, and flexor digitorum longus passes through this to reach the distal phalanx. The little toe muscles abductor and flexor digiti minimi brevis are inserted into the base of the proximal phalanx. On the dorsal surface an extensor expansion exists as in the hand, formed from extensor digitorum, the lumbricals and part of the interossei. The tendons of extensor digitorum brevis join the extensor expansions on the second, third and fourth toes (and sometimes the fifth). The tendons of the interossei are inserted directly into the bases of the proximal phalanges as well as into the extensor expansions.

SESAMOID BONES

The patella (p. 224) is the largest of all sesamoid bones. Like flexor pollicis brevis in the hand, the two tendons of the same muscle in the foot each have a sesamoid which is reciprocally grooved with the under surface of the head of the first metatarsal. There is usually one in the tendon of peroneus longus in the groove on the cuboid, and perhaps in the tendon of tibialis anterior just proximal to its attachment to the medial cuneiform. Any of the long tendons behind the malleoli may have a sesamoid, and so may the tibialis posterior tendon level with the head of the talus. The long flexor tendons to the toes may have sesamoids over the metatarsophalangeal or even the interphalangeal joints, especially the latter of the great toe. The fabella in the lateral head of gastrocnemius is a rare example of a sesamoid embedded in muscle rather than tendon.

OSSIFICATION OF FOOT BONES

All the foot bones ossify in cartilage. Three bones of the tarsus are ossified at birth. The calcaneus begins to ossify at the sixth month and the talus at the seventh month of fetal life. The cuboid ossifies in the ninth month, and the presence of this centre is acceptable medicolegal evidence of maturity (it is a convenience to look for this by a simple incision into the lateral side of the foot of a stillborn fetus). The navicular ossifies in the fourth year. The cuneiforms do not ossify in the order of their size; the lateral one ossifies in the first year, the medial in the third and the small intermediate in the fourth year. Metatarsals and phalanges ossify by shaft centres in utero, and their epiphyses are as in the hand (the epiphysis of the first metatarsal is at the base, that of each of the other four is in the head). These epiphyses ossify 2 or 3 years later than those in the hand, their centres appearing about the fifth year; but they join earlier (say 18 years).

There is a secondary centre on the posterior surface

of the calcaneus; it is a thin plate of bone that appears about the tenth year and joins at 18 years. The lateral tubercle of the talus, the tubercle at the base of the fifth metatarsal and the tuberosity of the navicular sometimes ossify as separate centres.

PART 15

COMPARISON OF UPPER AND LOWER LIMBS

The lower limb of man is built upon the same plan as the upper limb, and this is true of the hind limb and fore limb of all vertebrates. Modifications for functional needs produce very great differences in form and proportions (e.g. in the leg and wing of a bird or bat), but the basic pattern is the same. The student of human anatomy is well advised to review the upper and lower limbs together, since their similarities are so striking. Thigh and upper arm, leg and forearm, tarsus and carpus, foot and hand are all very similar in their bones, their muscles, their vessels and their nerves. They are developed from identical patterns in the embryonic limb buds.

THIGH AND ARM

The femur and humerus are articulated to the axial skeleton via the limb girdles. The femur articulates with three bones (ilium, ischium and pubis) at the acetabulum, the humerus with only two bones (scapula proper and coracoid) at the glenoid cavity. The acetabulum looks *back* and down; the femoral neck slopes up and *forward* to it, for the forward thrust of propulsion. The glenoid cavity looks forward around the chest wall; the head of the humerus faces back to it, to take the *backward* thrust of the upper limb. The hip joint is more stable than the shoulder joint at the expense of a certain loss of mobility in circumduction. The hind limb has become more extended and medially rotated from the fetal position of flexion than the upper limb, so that the extensor muscles of the thigh (quadriceps) lie in front while the extensor muscle of the arm (triceps) lies behind. Flexor and extensor compartments exist in both thigh and arm, with an abductor mass of muscle covering the hip and shoulder joints. The 'deltoid' of the hip consists of gluteus maximus and tensor fasciae latae, connected together by an intervening fascia. Beneath both deltoid muscles lie short muscles connecting the upper end of the bone to the limb girdle, namely the short scapular muscles in the upper limb

and the glutei medius and minimus, obturator muscles, etc., in the lower limb. In each case these short muscles are rotators, but their chief and most usual function is that of adjusting and stabilizing hip and shoulder while more distal parts of the limb are in motion.

In each limb certain of the flexor compartment muscles have become separated into an adductor compartment. In the thigh the adductors have been specialized into adductors longus, brevis and magnus, gracilis and part of pectineus, while in the arm the adductor mass of muscle has degenerated phylogenetically into the small coracobrachialis muscle condensed around the musculocutaneous nerve. This is not to say that adduction of the arm has been lost; indeed, the opposite is the case, for adduction is a very powerful movement in man. It is served by a new mass of muscle, the great sheets of the anterior and posterior walls of the axilla, pectoralis major and latissimus dorsi. In each limb the true adductor muscles are derived from the flexor compartment, and are thus supplied by anterior divisions of the anterior rami of the limb plexuses (obturator nerve and musculocutaneous nerve). The walls of the axilla, on the other hand, are supplied from both anterior and posterior divisions of the anterior rami; the anterior wall from the medial and lateral pectoral nerves and latissimus dorsi from the posterior divisions (posterior cord of brachial plexus). The latissimus dorsi is an extensor as well as an adductor (see p. 58).

The arterial supply of the thigh is essentially from the profunda femoris artery, the femoral artery itself passing on in the adductor canal to supply the leg and foot. A similar vessel, the profunda brachii, accompanies the radial nerve in the radial groove though the brachial artery itself, unlike the femoral, takes a considerable share, by other branches, in the supply of the arm. The venous and lymphatic returns are very similar in the two limbs and are dealt with together on page 238.

The pattern of nerve supply appears very different, for the reason that the embryological derivation of the muscles is somewhat different. Muscles of the upper limb are supplied from the brachial plexus, but the thigh extensors, functionally the counterpart of the triceps brachii, have a different embryological origin and thus, a different nerve supply. The five nerves of the lower limb plexus are L4, 5, S1, 2, 3 in the sacral plexus, and they do not supply the quadriceps and adductors, which are derived from muscle 'borrowed from the trunk'. This 'borrowed' muscle separates into extensor and flexor groups, whose nerves, the femoral and obturator, arise from the lumbar plexus and have no counterpart in the upper limb. Quadriceps femoris

and triceps brachii are functional counterparts but they are not morphologically homologous.

LEG AND FOREARM

Two bones support the structure of these limb segments. The preaxial bones, on the thumb and hallux side, are radius and tibia, the postaxial bones are ulna and fibula. Both preaxial and postaxial bones take part in forming the elbow joint and supination and pronation are free movements in the forearm. Only the preaxial bone takes part in forming the knee joint and pronation and supination are not possible in the leg. The two bones grip the talus at the ankle joint, which is thus greatly stabilized. The elbow is more stable than the knee from the purely bony point of view, but the latter joint is adequately strengthened by ligaments and tendons.

Despite the great functional modifications and differences between hand and foot, there is a most striking parallelism between the muscles of the forearm and leg. In the extensor compartment it is to be noted that the three tendons to the thumb (terminal phalanx, proximal phalanx and base of metacarpal) are inserted in a homologous way with those to the great toe (terminal phalanx, proximal phalanx and base of metatarsal) though their fleshy origins are very different in forearm and leg. The homologous muscles are extensor pollicis longus and extensor hallucis longus, extensor pollicis brevis and extensor hallucis brevis (of extensor digitorum brevis) and abductor pollicis longus and tibialis anterior.

The extensor tendons to the digits are similar. The extensor digitorum muscle arises from the humerus, the extensor digitorum longus arises in many animals from the femur though in man its origin has descended below the knee to the fibula. There are no real counterparts in the leg of the radial extensors of the wrist (extensors carpi radialis longus and brevis and extensor carpi ulnaris), though *functionally* there are similar extensors (i.e. dorsiflexors) of the ankle in tibialis anterior and peroneus tertius.

In the flexor compartments of these limb segments the muscle homologies are striking. Flexor digitorum superficialis has a wide origin from both forearm bones and from a fibrous arch between them. Soleus has a similar origin in the leg. Their insertions into the intermediate phalanges are similar, though in the case of soleus the muscle mass has been interrupted by the backward projection of the calcaneus upon which soleus acts as a flexor of the ankle joint, and a further muscle belly persists in the sole of the foot (flexor digitorum brevis) as the flexor of the intermediate phalanges. Superficial to these muscles the phylogeneti-

cally degenerating palmaris longus and plantaris muscles, each with a small belly and a long tendon, are traceable into the palmar and plantar aponeuroses. The gastrocnemius may be regarded as homologous with the carpal flexors, though it is unrealistic to pursue such similarities too far.

The vessels and nerves of forearm and leg are strikingly similar and especially is this so in the extensor compartments. The posterior interosseous nerve reaches the extensor compartment of the forearm by winding around the radius (preaxial bone) while the peroneal nerve reaches the extensor compartment of the leg by winding around the fibula (postaxial bone). The vessels in each case pass between the two bones of the forelimb. The posterior tibial vessels and nerve pass beneath the fibrous arch of soleus while the ulnar artery and median nerve pass beneath the fibrous arch of flexor digitorum superficialis.

TARSUS AND CARPUS

These consist of similar bones, though variations in size and arrangement make their form very dissimilar. The carpus is a mechanism for articulating hand to radius and allowing circumduction to occur, the tarsus is adjusted as a mobile weight-bearing and propulsive mechanism.

The primitive mammalian arrangement of the bones (Figs 3.65–3.68) is:

- (1) A proximal row of three bones (radiale or tibiale, intermediale, ulnare or fibulare).
- (2) A distal row of five bones, one for each metacarpal or metatarsal.
- (3) A central bone (os centrale) between the two rows.

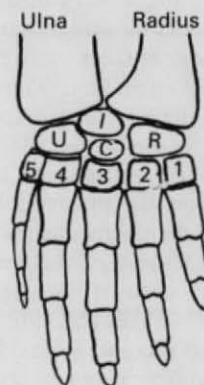


Fig. 3.65 Primitive arrangement of carpal bones in vertebrates, as seen in the manus of the water tortoise. R — os radiale, I — os intermediale, C — os centrale, U — os ulnare, 1–5 — distal row of carpal bones.

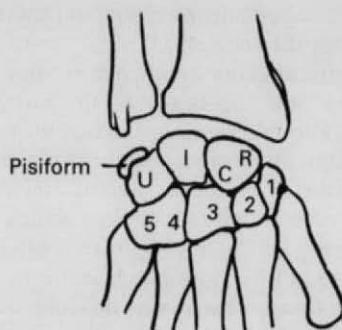


Fig. 3.66 Human carpal bones. The os radiale and centrale (R and C) have fused to form the scaphoid. The fourth and fifth bones of the distal row have fused to form the hamate. The pisiform appears as an extra bone, a sesamoid in the tendon of flexor carpi ulnaris; it has no counterpart in the foot.

In all tetrapods it is normal to find the two postaxial bones of the distal row fused into one bone, the hamate for fourth and fifth metacarpals and cuboid for fourth and fifth metatarsals. The human carpal scaphoid is the fused os radiale and os centrale, and fracture of the scaphoid usually separates these two elements. In the tarsus the os centrale becomes the navicular. In the carpus the os intermediale becomes the lunate, in the tarsus it becomes the lateral tubercle of the posterior process of the talus (Figs 3.65–3.68).

The functional differences between wrist and ankle should be noted. In addition to flexion and extension the wrist has abduction and adduction, while at the ankle joint movement is limited to flexion and extension. Movements between the talus and the other tarsal bones provide the important side-to-side movements of

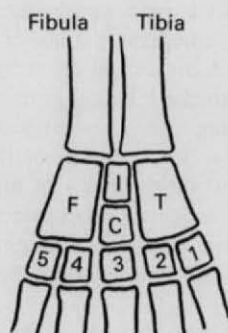


Fig. 3.67 Primitive arrangement of the tarsal bones. T — os tibiale, I — os intermediale, C — os centrale, F — os fibulare, 1–5 — distal row of tarsal bones. Compare with Figure 3.65.

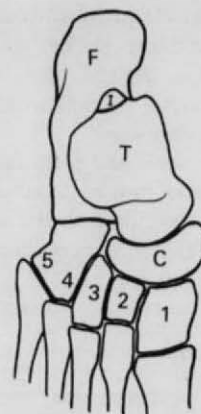


Fig. 3.68 Human tarsal bones. The os tibiale and intermediale (T and I) have fused to form the talus. The os fibulare (F) has become the calcaneus, the os centrale (C) the navicular. The fourth and fifth bones of the distal row have fused to form the cuboid.

eversion and inversion, and these replace the movements of pronation and supination which occur in the forearm. The movements of inversion and eversion are essential to an efficient 'grip' of the foot when walking across uneven or laterally sloping smooth surfaces, or when leaning over while turning at speed on horizontal surfaces.

FOOT AND HAND

While the hand consists of metacarpals and phalanges the foot includes also the tarsal bones. In the hand the first metacarpal with its two phalanges has 'broken free' and can be opposed to the other four, thus enabling objects to be gripped. The thumb is thus, functionally, as important as all four other digits combined. In contrast, the foot is relatively fixed, and the first metatarsal bone has little power of free movement. All five metatarsals are weight bearing and in propulsion it is the big toe side from which the 'take off' is made. This has resulted in a shifting of the axis of the human foot towards the tibial side and the longitudinal axis of the foot passes through the *second metatarsal*, while in the hand the axis remains the *middle* (i.e. *third*) metacarpal. In spite of these bony and functional differences the arrangements of muscles, vessels and nerves in the sole and palm are strikingly similar. In each a powerful aponeurosis gives concavity to palm and sole and serves for attachment of skin to improve the grip. The hand and foot each contain four muscle layers. Beneath the aponeurosis lies a group of

small (intrinsic) muscles, beneath these the long flexor tendons pass to the digits. Deeper still are the adductor muscles of thumb or big toe, while deep to this third layer lie the metacarpals or metatarsals with their intervening interosseous muscles.

The *nerves* of the sole and palm are almost identical in their sensory and motor distribution. The lateral plantar nerve corresponds with the ulnar nerve in the palm and the medial plantar nerve corresponds with the median nerve in the hand.

Cutaneous branches

The skin of the postaxial one and a half digits is supplied in the sole by the lateral plantar nerve, and in the palm by the ulnar nerve. The skin of the preaxial three and a half digits is supplied in the sole by the medial plantar nerve and in the palm by the median nerve. In each digit of the hand and foot the nerves of the flexor skin extend around the tip to the dorsal surface, where they supply the extensor skin up to a level proximal to the nail bed.

Motor branches

The distribution of the medial plantar and median nerves is similar, for each supplies intrinsic flexor and abductor muscles of the first digit (big toe or thumb). The medial plantar nerve supplies the first lumbrical muscle, the median nerve usually supplies the first two lumbrical muscles. There is less resemblance between the motor distribution of the lateral plantar nerve and the ulnar nerve, though each divides into a superficial and a deep branch. The superficial branch of the ulnar supplies no muscle except the little palmaris brevis, while that of the lateral plantar supplies flexor digiti minimi brevis and the interossei of the fourth space; but in each case the deep branch supplies all the remaining muscles of sole and palm.

The dorsum of the foot contains the extensor tendons lying bound together by the deep fascia and this is so in the hand also. The extensor digitorum brevis of the foot has its counterpart in the hand, but the latter serves only the index finger. It is the extensor indicis, arising from the ulna.

There is much similarity in the vascular patterns. The dorsal venous arches are similar in the hand and foot, and each collects most of the blood from palm and sole.

VENOUS RETURN IN THE LOWER AND UPPER LIMBS

In each limb the venous return is by way of large veins

that lie in the subcutaneous tissue and by deep veins that accompany the arteries.

The **superficial veins** commence in a dorsal venous arch that lies over the heads of the metatarsals or metacarpals. The arch receives much of the blood from the sole or palm, not only around the margins of foot or hands, but also by *veins that perforate the interosseous spaces*. Thus pressure on the sole in standing or on the palm in gripping fails to impede venous return. A vein leaves each side of the dorsal arch and runs up in the subcutaneous tissue. These veins lie along the preaxial and postaxial borders of the limbs. The preaxial vein of the lower limb is the great saphenous, that of the upper limb the cephalic. Each runs proximally to the root of the limb, where it pierces the deep fascia to open into the main vein of the limb. The postaxial vein of the lower limb is the small saphenous, that of the upper limb the basilic. Each runs up in the subcutaneous tissue of the forelimb and pierces the deep fascia to join, in the case of the former the popliteal vein, and in the case of the latter, the brachial vein.

The **deep veins** accompany the arteries. In foot and hand, in leg and forearm, they consist of *venae comitantes*, a vein lying to each side of the artery. They communicate by frequent transverse channels. Towards knee and elbow the *venae comitantes* flow into a single vein, which remains single throughout the rest of its course. In the lower limb the popliteal vein is a single one, in the upper limb the veins do not unite into a single trunk until about the middle of the arm.

LYMPHATIC DRAINAGE OF LOWER AND UPPER LIMBS

In each limb the rule applies that superficial lymphatics follow veins, while deep lymphatics follow arteries. The lymph is taken to lymph nodes lying in groin and axilla. The superficial lymphatics of the *lower limb* accompany the great and small saphenous veins (Fig. 3.4). Infections of the superficial tissues of the foot are common; lymphadenitis, when it occurs, is limited almost exclusively to the inguinal nodes and popliteal lymphadenitis is quite rare. This is because practically all the superficial tissues and skin of the lower limb drain to the groin along the route of the great saphenous veins; only a very small area of skin and subcutaneous tissue over the heel drains alongside the small saphenous vein to the lymph nodes in the popliteal fossa.

The superficial lymphatics along the course of the great saphenous vein drain into nodes lying in a vertical chain along the termination of the vein. The remaining nodes of the groin, lying lateral and medial to the

saphenous opening, receive lymph from the lateral side of the trunk and from the back below the waist and from the anterior abdominal wall and perineum respectively (cf. the three groups in the axilla).

All the lymph from the superficial inguinal nodes passes by efferent vessels through the cribriform fascia to deep inguinal nodes, lying beneath the fascia lata to the medial side of the femoral vein. These receive also the deep lymphatics of the lower limb that have ascended alongside the arteries, some having passed through the popliteal nodes. In turn they send their efferents through the femoral canal to the nodes along the external iliac artery.

In the *upper limb* the grouping of the lymph nodes in the axilla and the areas they drain show great similarity

(p. 69). The lateral group of nodes receives practically all the lymph from the upper limb. The nodes lie along the medial side of the axillary vein and correspond to the vertical group of superficial inguinal nodes. The anterior or pectoral group of axillary nodes receive lymph from the breast and anterior body wall as far down as the waist (umbilicus) and they correspond with the medial group of superficial inguinal nodes. The posterior or scapular group of axillary nodes receive lymph from the back as far down as the waist and they correspond with the lateral group of superficial inguinal nodes. Just as all three groups of superficial inguinal nodes send their lymph to the deep inguinal group, so all three groups of axillary nodes send theirs to the apical group.

4. Thorax

PART 1 BODY WALL

Though very different functionally, the wall of the thorax and the wall of the abdomen are one, topographically and developmentally, the essential difference being the presence of ribs in the part primarily concerned with respiration. Many features can be considered together.

SKIN AND SUBCUTANEOUS TISSUE

The **skin** varies in texture, tending to be thin in front and thick behind. Distribution of hair varies with sex, age and race. Natural tension lines of the skin are very constant, and are of tremendous importance to the cosmetic appearance of healed incisions. An incision along a tension line will heal as a hairline scar, virtually invisible; an incision across the lines will tend to heal with either a wide or a heaped-up scar. The tension lines run almost horizontally around the body wall (Fig. 1.2, p. 3).

The **subcutaneous tissue** is the same as elsewhere in the body (p. 3). Fat is contained in loculi, whose fibrous walls connect the overlying dermis to the underlying deep fascia. There is an exception over the dilatable part of the body wall, namely the anterior abdominal wall and lower part of the thoracic wall in front of the midaxillary lines. Here the fibrous septa of the subcutaneous tissue are condensed beneath the fat into a thin but strong membrane, properly called the membranous layer of superficial fascia, but still often known by its old name, the fascia of Scarpa. This fascia allows the subcutaneous fat (or fatty layer of superficial fascia, previously called the fascia of Camper) to slide freely over the underlying thoracic wall, rectus sheath, and external oblique aponeurosis. It fades out over the upper thoracic wall and along the midaxillary lines.

Below, over the thighs, it is attached to the fascia lata along the flexure skin crease of the hip, extending from the pubic tubercle obliquely outwards just *below* the inguinal ligament. The fascia of Scarpa is attached to the sides of the body of the pubic bone and is continued over the penis and scrotum, where it receives a different name, the superficial perineal fascia of Colles (p. 406).

Blood supply

The intercostal and the lumbar arteries pass forward in the neurovascular plane (p. 21) to supply the flanks; the internal thoracic and the superior and inferior epigastric arteries supply the ventral midline tissues. From all these arteries cutaneous branches pass to the superficial fat and skin. The *venous return* from the subcutaneous tissue does not follow the arteries. The blood is collected by an anastomosing network of veins that radiate away from the umbilicus. Below this level they pass to the great saphenous vein in the groin, above the umbilicus they run up to the lateral thoracic vein and so to the axillary vein. A few at the umbilicus drain the lower part of the ligamentum teres. The upper part of this ligament drains to the left branch of the portal vein; these *para-umbilical veins* may distend in portal obstruction, giving rise, if the distension spreads to the subcutaneous veins, to the *caput Medusae*. A longitudinal channel uniting the lateral thoracic veins with the superficial epigastric vein above the inguinal ligament can often be recognized in cases of obstruction of the inferior vena cava; it constitutes the *thoraco-epigastric vein* and provides a communication between superior and inferior venae cavae.

Lymph drainage

Lymphatic channels from the subcutaneous tissue and skin follow the veins, to axillary and superficial inguinal nodes. From above the level of the umbilicus, lymph from the front of the body goes to the pectoral lymph

nodes, from the back of the body to the scapular nodes. (For lymph drainage of breast, see p. 71). From below the umbilicus lymph from the anterior aspect of the abdominal wall and perineum goes to the medial group of superficial inguinal nodes, and from the lateral and posterior aspects of the abdominal wall to the lateral group.

Nerve supply

Above the second rib, the skin is supplied by supraclavicular branches of the cervical plexus (C4, Fig. 1.12, p. 20). Below this level a midline strip of ventral skin is supplied by the *anterior cutaneous branches* of the spinal nerves from T2 to L1, which latter supplies suprapubic skin. A broad lateral strip is supplied by the *lateral cutaneous branches* of the spinal nerves from T2 or 3 to L1; these branches emerge in the midaxillary line. Their anterior and posterior branches each innervate an oblique zone of skin in regular sequence. Note that the lateral cutaneous branches of T12 and the iliohypogastric nerve descend over the iliac crest to supply the skin of the buttock. The ilioinguinal nerve has no lateral cutaneous branch; it is the collateral branch of the iliohypogastric, both coming from L1 nerve. A posterior strip of skin is innervated by the *posterior rami* of spinal nerves, by their medial branches in the upper part and their lateral branches in the lower part (Fig. 1.11, p. 20).

MORPHOLOGY OF BODY WALL MUSCLES

The myotomes of the trunk developed from the segmentation of mesoderm divide into dorsal and ventral parts, innervated by dorsal (posterior) and ventral (anterior) rami of spinal nerves respectively. The dorsal muscle masses become the erector spinae group, hence their innervation by posterior rami. The ventral parts of the segments form three layers of muscles which encircle most of the body cavity, their fibres lying in different degrees of obliquity, with the nerves (and segmental vessels) between the middle and inner layers. The thoracic layers are reinforced with bony condensations (ribs). All three layers are supplied by anterior rami. The outer layer forms the external intercostal and serratus posterior muscles in the thorax and the external oblique in the abdomen (in the neck it forms scalenus posterior). The middle layer forms the internal intercostals in the thorax and the internal oblique in the abdomen (in the neck, scalenus medius). The inner layer forms the transversus thoracis group (innermost intercostals, transversus thoracis and subcostals, and the diaphragm which migrates

caudally), and in the abdomen transversus abdominis, quadratus lumborum and levator ani (in the neck scalenus anterior, longus capitis and longus cervicis). However, near the midline the layers fuse, forming rectus abdominis in the abdomen and geniohyoid and the strap muscles in the neck; the thoracic representative of this fusion is the occasional rectus sternalis (Fig. 2.2, p. 55). The muscles of the limbs are generally believed to be developed from limb bud mesoderm, without contributions from trunk myotomes.

PART 2

THORACIC WALL AND DIAPHRAGM

The skin and subcutaneous tissue of the thoracic wall having been studied (p. 241), it now remains to consider the muscles and skeletal structures. Details of the thoracic part of the vertebral column are given on page 539, and of thoracic vertebrae on page 548.

THORACIC BONES AND CARTILAGES

The skeleton of the thoracic wall consists of the 12 thoracic vertebrae, the 12 pairs of ribs and costal cartilages and the sternum. The thoracic cavity is roofed in above the lung apices by the suprapleural membrane and is floored by the diaphragm. The floor is highly convex (domes of the diaphragm), so that the volume of the thoracic cavity is much less than inspection of the bony cage would suggest. The liver and spleen and the upper parts of the stomach and both kidneys lie in the abdominal cavity wholly or partly covered by ribs.

Ribs are used for breathing. The purpose of studying their joints and their muscles is to understand how this is brought about. Ribs are not primarily protective (heart and lungs are no more sensitive to external violence than 'unprotected' abdominal viscera and modern thoracic surgery is not inhibited by them). Perhaps ribs are protective in fish — against increased hydrostatic pressure. In snakes they are organs of locomotion — the rib-ends act as feet inside the skin, instead of outside as in the invertebrate centipede. But in air-breathing mammals the primary function of ribs is respiratory.

THORACIC JOINTS

At the back the ribs articulate with the vertebral column in two places: by their heads (joints of the heads of the ribs) and by their tubercles (costotransverse joints).

Collectively these form the **costovertebral joints**. At the front the ribs join their costal cartilages (costochondral joints). The upper seven costal cartilages articulate with the sternum at the sternocostal joints, the next three articulate with each other (interchondral joints) and the last two are free. The manubriosternal joint is a symphysis between the manubrium and body of the sternum, and the xiphisternal joint is a symphysis between the body and the xiphoid process.

Joints of the heads of the ribs

The head of a typical rib possesses two articular facets that slope away from each other, separated by a ridge. Each facet makes a small synovial joint with a demifacet of a vertebral body; the lower rib facet with the upper costal facet of its own vertebra, and the upper facet with the lower costal facet of the vertebra above (Fig. 4.1). The ridge between the two is attached to the intervertebral disc by the *intra-articular ligament*. The front of the capsule of the synovial joints is reinforced by the *radiate ligament* which consists of three bands. The upper band passes across the joint to the body of the vertebra above, and the lower band to the vertebra below. The central band runs horizontally, deep to the anterior longitudinal ligament and across the intervertebral disc with which it blends, to join with fibres from the other side. This arrangement, known as the *hypochordal bow*, is of morphological interest since it explains the formation of the anterior arch of the atlas (p. 541). Note that the first rib articulates with T1 vertebra only, never coming into contact with C7, and the last two ribs also articulate only with their own vertebrae. In these instances the radiate ligament consists of two bands, not three.

Costotransverse joints

The tubercle of a typical rib (p. 290) has two facets. The medial facet, covered with hyaline cartilage, articulates with a facet near the tip of the transverse process

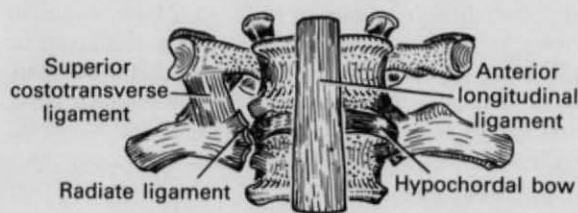


Fig. 4.1 Joints of the heads of the ribs from the front. The upper vertebra shows the articular facet on the transverse process for the costotransverse joint with the tubercle of a rib.

of its own vertebra, so forming a small synovial joint with its own *capsule*. In the upper six ribs and transverse processes these articular surfaces are reciprocally curved but lower down the series they are flat; these differences have implications for thoracic movements (p. 251). The lateral facet (non-articular) gives attachment to the *lateral costotransverse ligament* which runs to the tip of the transverse process and is one of three ligaments helping to stabilize the joint. The other two are the *costotransverse ligament*, which occupies the space between the back of the neck of the rib and the front of the transverse process, and the *superior costotransverse ligament*, which passes as two laminae from the crest of the neck of the rib to the under surface of the transverse process of the vertebra above (Fig. 4.1). The anterior lamina is continuous with the posterior intercostal membrane; the posterior is in the same plane as the external intercostal muscle. Note that there are *three* ligaments called costotransverse — the costotransverse, the *lateral* costotransverse and the *superior* costotransverse. The lower two ribs make no synovial joints with transverse processes; the attachments are only ligamentous.

Costochondral joints

Every rib makes with its costal cartilage a primary cartilaginous joint. The costal cartilage represents no more than the unossified anterior part of a rib. The anterior end of the bony rib is deeply concave to receive the reciprocally convex end of the costal cartilage. No movement takes place at these joints.

Interchondral joints

Costal cartilages 6 and 7, 7 and 8, and 8 and 9 are joined to parts of adjacent surfaces of each other by small synovial joints, with their capsules reinforced by a few ligamentous fibres.

Sternocostal joints

These joints are misleadingly named since they are between the sternum and costal cartilages, not the ribs, so sternochondral would be a more appropriate term. The first joint is exceptional in that the first costal cartilage articulates with the manubrium by a *primary cartilaginous joint* (Fig. 4.2). The cartilage is short and thick and capable of very little distortion. Thus the manubrium and the first ribs are fixed to each other and move together as one. This fixation is necessary to give stability to the clavicle and so to the pectoral girdle and upper limb (p. 63).

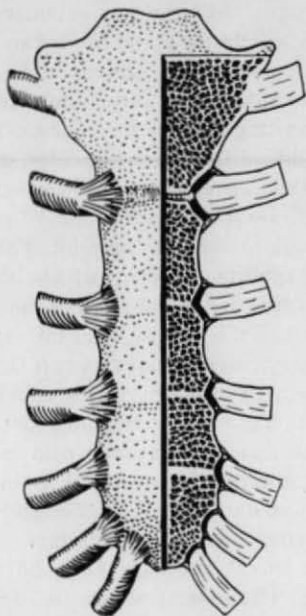


Fig. 4.2 Sternocostal joints. Part of the sternum has been sectioned to show that the first is a primary cartilaginous joint and the others are synovial; the second is double.

The next six costal cartilages each articulate with the sternum by a *synovial joint* — a single cavity except in the case of the second, where the cavity between the cartilage and manubrium is separate from that between the cartilage and body (Fig. 4.2).

Manubriosternal joint

At this *symphysis* between the manubrium and body of the sternum, the surfaces are covered by hyaline cartilage and there is an intervening disc of fibrocartilage which often becomes ossified in later life, but without fusion of the bones so that for respiratory purposes (p. 252) joint movement is maintained even in old age. Frequently (30%) cavitation appears in the disc so that the joint may appear to be synovial, but this is simply a degenerative change that does not alter the fact that the joint is a symphysis.

Xiphisternal joint

This is another symphysis, between the body of the sternum and the xiphoid process, with cartilage-covered surfaces and a fibrocartilaginous disc. Ossification from middle age onwards is common.

THORACIC MUSCLES

The **muscles of the thoracic wall** lie in the same three morphological layers as those of the abdominal wall (pp. 242 and 295), but in the thoracic region they have become divided up by the presence of ribs that have grown out from the primitive vertebral arches into positions between the muscle somites (myotomes). As might be expected they are innervated segmentally by anterior rami. The *outer* thoracic layer forms the external intercostal muscles, corresponding to the single external oblique in the abdomen, but appears also to include the two small serratus posterior muscles which lie external to the erector spinae mass of the vertebral column. The *middle* layer forms the internal intercostals, corresponding to the single internal oblique. The *inner* layer is broken up into three groups of muscles, the subcostals, innermost intercostals and the transversus thoracis. This incomplete layer may be referred to, as a whole, as the transversus thoracis group. Between it and the middle layer is the neurovascular plane, continuous with that of the abdominal wall; in it run intercostal vessels and nerves, with their collateral branches (Fig. 1.10, p. 19).

Outer layer

Two small muscles of the external layer do not attach themselves between ribs but extend medially to the vertebral column. They are the posterior serratus muscles. Supplied like the rest of the layer by anterior rami, they have migrated posteriorly, and lie on the surface of the erector spinae mass. Each arises from four spinous processes, two in the thorax and two beyond it, and each is inserted into four ribs just lateral to the erector spinae, i.e. just lateral to the angles of the ribs.

Serratus posterior superior arises from the spinous processes of the lowest two cervical and the upper two thoracic vertebrae and from the intervening supraspinous ligaments. The flat sheet of muscle slopes downwards on the surface of splenius and is inserted just lateral to the angles of ribs 2–5. Many tendinous fibres in the sheet of muscle give it a characteristic glistening appearance which provides a useful landmark in exposures of this region. The dorsal scapular nerve and vessels run down on the muscle, which is covered by levator scapulae and the rhomboids (Fig. 2.6, p. 59).

Serratus posterior inferior arises from the lower two thoracic and the upper two lumbar spinous processes and from the intervening supraspinous ligaments. The origin is an aponeurosis which fuses with the posterior lamella of the lumbar fascia deep to

latissimus dorsi. The flat sheet of muscle lateral to the aponeurosis slopes upwards in contact with the thoracolumbar fascia and is inserted just lateral to the angles of the lowest four ribs.

The serratus posterior muscles are weak muscles of respiration. The superior muscle elevates the upper ribs (inspiration) while the inferior muscle depresses the lower ribs (expiration).

Although morphologically associated with the muscles of the back (p. 543), the **levator costae** muscles are functionally classified as thoracic muscles and so must be mentioned here. Each one of each of the 12 pairs is fan-shaped, spreading down from near the tip of a transverse process (from C7 to T11 vertebra) to be inserted into the upper border of the rib below, lateral to its tubercle. Thus one passes to each rib and presumably helps to elevate it. They are the *only thoracic muscles to be supplied by the posterior*

rami of spinal nerves (from C8 to T11), in keeping with their developmental origin.

The remaining muscles of the outer layer are the **external intercostals**. Examine a rib (Fig. 4.38). Note that the costal groove is bounded externally by a lip that projects downwards; internally the groove possesses a rounded border. The upper border of the rib is smoothly rounded. The fibres of the external intercostal muscles pass obliquely downwards and forwards from the sharp lower border of the rib above to the smooth upper border of the rib below (Fig. 4.4). Each muscle extends from the superior costotransverse ligament at the back of the intercostal space as far forwards as the costochondral junction; here it is replaced by the *anterior intercostal membrane* (Fig. 4.3). This extends to the side of the sternum. Between the bony ribs is muscle; between the costal cartilages is membrane.

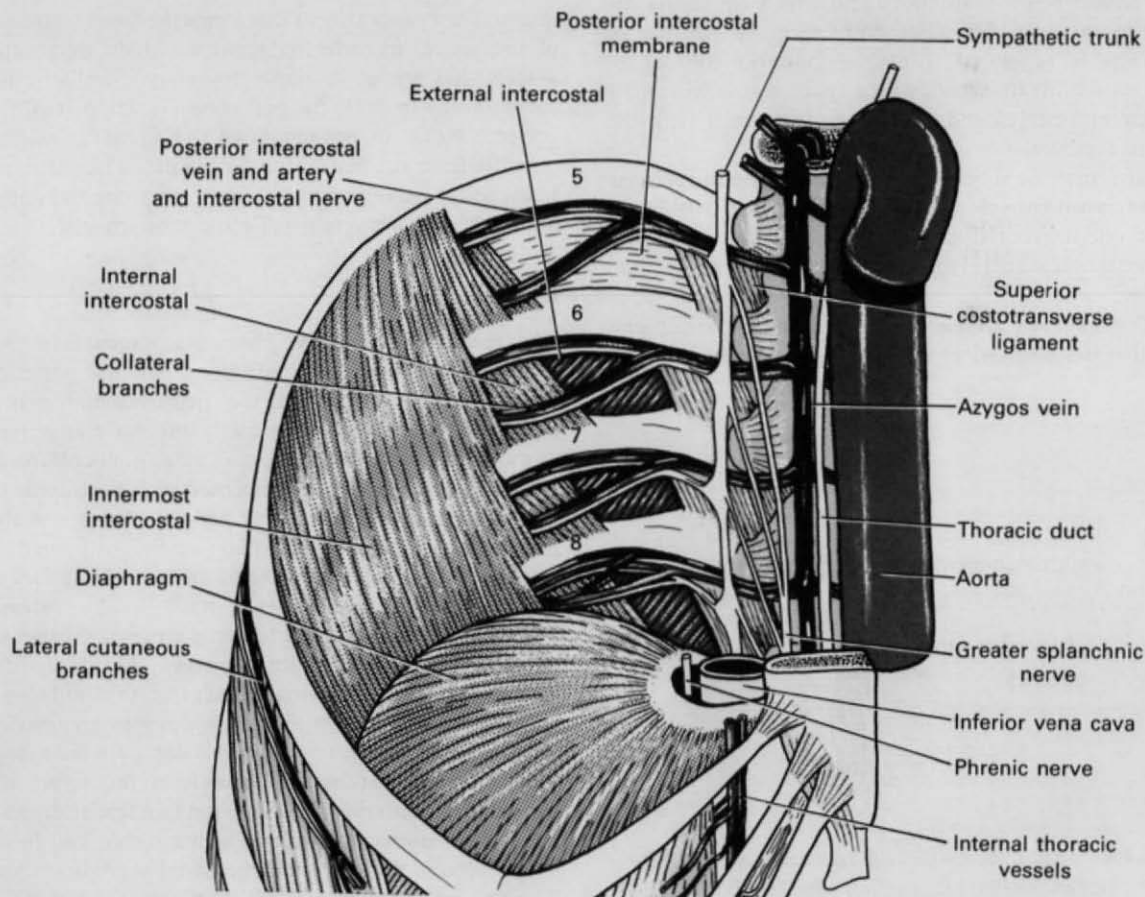


Fig. 4.3 Part of the thoracic wall on the right. The subcostal muscles have been removed to expose the 'paravertebral gutter'.

Middle layer

This consists of the **internal intercostal muscles**. The fibres run downwards and backwards, from the costal groove to the upper border of the rib below (Fig. 4.3). Each muscle, unlike an external intercostal, extends as far forwards as the side of the sternum; it is replaced posteriorly by the *posterior intercostal membrane*, which extends from the angle of the rib to the superior costotransverse ligament at the posterior limit of the space (Fig. 4.3).

Inner layer

Of the three groups of muscles in this layer (Fig. 4.4), the innermost intercostals line the rib cage at the side, with the subcostals at the back, and the transversus thoracis at the front.

Lying in the paravertebral gutter are fibres, each crossing more than one intercostal space, that are better developed below than above and which constitute the **subcostal muscles**. The thin sheet of muscle so formed is separated from the posterior border of the innermost intercostals by a space across which the intercostal nerves and vessels are in contact with the parietal pleura.

Similar to the subcostals, the fibres of the **innermost intercostal muscles** (intercostales intimi) cross more than one intercostal space. They lie on the lateral part of the thoracic wall (Fig. 4.3), and are wider below than above.

Transversus thoracis arises from the lower end of the sternum, whence digitations diverge on each

side, one to each costal cartilage from the second to the sixth inclusive. This muscle was formerly called *sternocostalis*, which was a more exact name. The *transversus thoracis group* is the best inclusive name for all three groups of the innermost layer because it conforms with the *transversus abdominis* muscle, with which it is morphologically identical.

The actions of thoracic muscles are considered on page 251.

INTERCOSTAL SPACES

The intercostal spaces (between the ribs) are filled in by the muscles of the three layers described above. Running in the plane between the intermediate and inner layers are the intercostal nerves and vessels (Fig. 4.4). The order from above downwards is vein, artery, nerve, all three being protected by the downward projection of the lower border of the rib. Thus a needle or trocar for pleural drainage (p. 281) is inserted just *above* the rib that forms the *lower* boundary of the space, in order to avoid the main nerve and vessels that are at its *upper* boundary. Similarly, for thoracotomy (p. 254) the periosteum is stripped off the upper half of a rib, not the lower, to keep as far away as possible from the neurovascular bundle. The collateral branches of nerve and vessels that run along the upper border of a rib are very small and can be ignored.

Intercostal nerves

The mixed **spinal nerve**, having emerged from the intervertebral foramen and given off its posterior ramus, passes around in the neurovascular plane, between the internal intercostal and the transversus thoracis group of muscles. It gives off a small **collateral branch**, which is wholly concerned with the supply of the muscles of the space, the parietal pleura and the periosteum of the ribs and has no cutaneous branch. It runs just above the rib that forms the lower boundary of the space. The main nerve itself has a **lateral cutaneous branch** and a terminal anterior cutaneous branch. The lateral branch pierces the intercostal muscles and the overlying muscles of the body wall along the midaxillary line, and divides into an anterior and posterior branch to supply the skin over the space. The **anterior cutaneous branch** in the upper six spaces passes anterior to the internal thoracic artery and pierces the intercostal muscles to reach the skin. In its course around the space the intercostal nerve lies below the vein and artery (see above). In its course around the body wall the main nerve lies in a wider circle that embraces the narrower circle of the intercostal vessels;

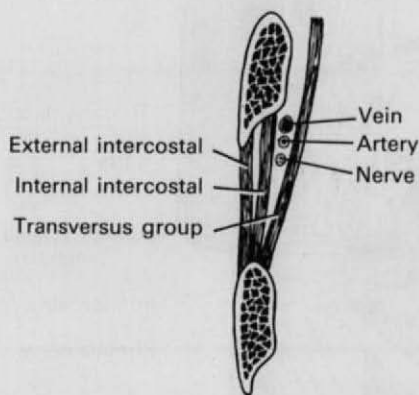


Fig. 4.4 Vertical section through an intercostal space. The neurovascular structures (vein, artery, nerve from above downwards) lie between the internal intercostals and the transversus group. The small collateral branches (not shown) are in the same plane just above the lower rib.

where the nerve crosses the artery it will always be nearer the skin (Fig. 1.10). At the back of the intercostal space the nerve crosses behind the artery; at the front of the space the nerve crosses in front of the internal thoracic artery. Between these points the nerve is confined in the neurovascular plane below the artery.

The lower five intercostal nerves and their collateral branches slope downwards behind the costal margin into the neurovascular plane of the abdominal wall, which they supply (as described on p. 300).

The **first intercostal nerve** is very small. It courses around beneath the flat inferior surface of the first rib (Fig. 6.7B, p. 443), some distance inside the external border of the rib, in contact with the endothoracic fascia and pleura. It supplies the intercostal muscles of the first space with motor and proprioceptive fibres, and the adjacent pleura and rib periosteum with sensory fibres. Note that the first intercostal nerve

supplies no skin, lacking both lateral and anterior cutaneous branches.

The **subcostal nerve** (twelfth thoracic), although arising in the thorax, quickly leaves by passing behind the lateral arcuate ligament into the abdomen, below the subcostal artery and vein, and is described on page 360.

Intercostal arteries

Arteries enter intercostal spaces at the back and front. At the back the upper two spaces are supplied by the **superior intercostal artery**. This is the descending branch of the costocervical trunk, which comes off from the second part of the subclavian artery (Fig. 4.5) behind scalenus anterior. It enters the thorax by passing across the front of the neck of the first rib; here it has the sympathetic trunk on its medial side, while the first thoracic nerve passes laterally across the first rib to join

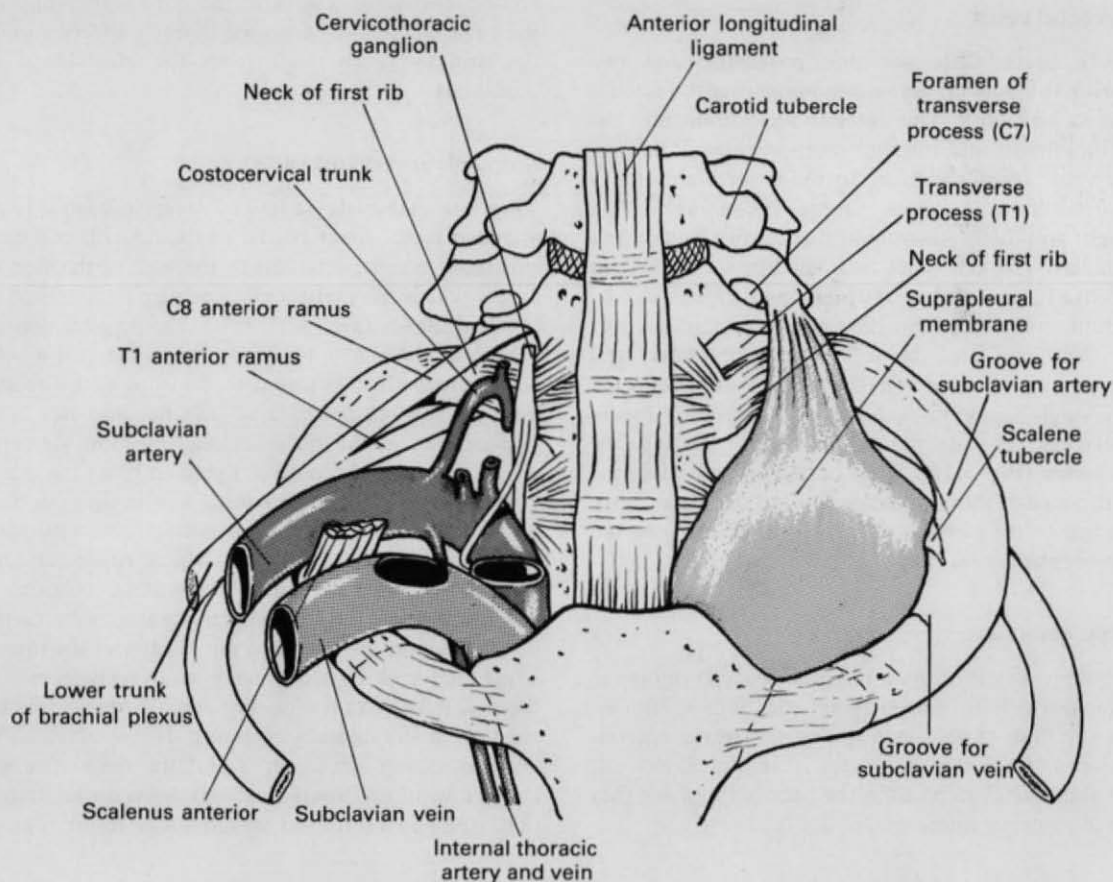


Fig. 4.5 Thoracic inlet and the suprapleural membrane. The membrane, on which the subclavian vessels lie, has been removed on the right.

the brachial plexus. The supreme intercostal vein lies between the artery and the sympathetic trunk. At this point the sympathetic trunk frequently presents the cervicothoracic (stellate) ganglion, a fusion of the first thoracic with the inferior cervical ganglion.

The remaining nine intercostal spaces are supplied each with a separate branch of the descending thoracic aorta. All 11 arteries constitute the **posterior intercostal arteries**. Each gives off a small collateral branch, which passes around in the neurovascular plane at a lower level than the main trunk.

At the front of the intercostal space the internal thoracic artery in the upper six spaces and the musculophrenic artery in the seventh, eighth and ninth spaces give off two **anterior intercostal arteries** that pass backwards and make an end-to-end anastomosis with the posterior vessels, which are larger than the anterior. There are no anterior intercostal arteries in the last two spaces.

Intercostal veins

In each space there are one **posterior** and two **anterior intercostal veins**, accompanying the arteries of the same names. The anterior veins drain into the musculophrenic and internal thoracic veins. The posterior veins are not regular. In the lower eight spaces they drain into the azygos system: the azygos vein on the right and the hemiazygos and accessory hemiazygos on the left. The first space is drained by the highest or **supreme intercostal vein** which opens either into the vertebral vein or the brachiocephalic vein of its own side. The blood from the second and third intercostal spaces, and sometimes from the fourth also, is collected into a single trunk on each side, the **superior intercostal vein**. That on the right drains simply into the azygos vein (Fig. 4.14). That on the left runs forward over the arch of the aorta, superficial to the vagus nerve and deep to the phrenic nerve, to empty into the left brachiocephalic vein (Fig. 4.15).

Lymph drainage

The lymph vessels of the intercostal space conform to the general rule that deep lymphatics follow arteries. From the front of the space vessels pass to the anterior intercostal (parasternal) nodes that lie along the internal thoracic artery; from the back of the space they drain to posterior intercostal nodes (p. 279).

Internal thoracic artery

From the first part of the subclavian artery, the

internal thoracic artery (formerly the internal mammary) passes vertically downwards a finger's breadth from the border of the sternum. It gives off two **anterior intercostal arteries** in each intercostal space. At the costal margin it divides into the **superior epigastric** and **musculophrenic arteries**. The former passes lateral to the xiphisternal fibres of the diaphragm to enter the rectus sheath behind the muscle. The latter passes along the costodiaphragmatic gutter and gives off two anterior intercostal arteries in each space; it ends by piercing the diaphragm to ramify on its abdominal surface. The internal thoracic artery is accompanied by two *venae comitantes* that empty into the brachiocephalic vein.

The artery gives off a *pericardiophrenic branch* that runs with the phrenic nerve and supplies branches to the nerve itself, pleura and fibrous and parietal pericardium.

Perforating branches emerge towards the surface from each intercostal space. They are especially large in the second and third spaces of the female for supply of the breast. Thus the internal thoracic artery supplies the anterior body wall from the clavicle to the umbilicus.

Suprapleural membrane

This is a rather dense fascial layer (Sibson's fascia) attached to the inner border of the first rib and costal cartilage. It is *not* attached to the *neck* of the first rib, across which the first thoracic nerve passes to join the brachial plexus (Fig. 4.5). It has the cervical dome of the pleura attached to its under surface, and when traced medially it is found to thin out and disappear into the mediastinal pleura. It is flat and lies in the oblique plane of the thoracic inlet, projecting scarcely at all into the root of the neck. Lying on it are the subclavian vessels and other structures seen in the root of the neck (p. 255). Its posterior attachment is to the transverse process of C7 vertebra, where muscular fibres may be found in it. This is the *scalenus minimus* (or *pleuralis*) muscle, and the suprapleural membrane is to be regarded as the flattened-out tendon of the muscle. The function of the membrane is to give a rigidity to the thoracic inlet that prevents distortion during respiratory changes of intrathoracic pressure. If it were not a flat and unyielding structure, it and the neck structures above it would be 'puffed' up and down during respiration. Actually it is moved only in forced respiration.

DIAPHRAGM

The **diaphragm** is a thin sheet of muscle caudal to the

lungs. Its purpose is essentially for inspiration. It is present only in placentalia.

Morphologically the diaphragm is a derivative of the inner (transversus) layer of the muscles of the body wall. In the mammals this innermost sheet descended from the thoracic inlet to the lower margin of the thoracic cage. Embryologically a similar descent occurs. Being derived from the inner layer, its fibres arise in continuity with those of transversus abdominis from within the costal margin. It is completed behind the costal origin by fibres that arise from the arcuate ligaments and the crura. From the circumference of this oval origin the fibres arch upwards into a pair of domes and then descend to a central tendon which has no bony attachment.

Viewed from in front the diaphragm curves up into right and left domes. The right is higher than the left, ascending in full expiration as high as the nipple (fourth space), while the left dome reaches the fifth rib (Fig. 4.6). The central tendon is level with the xiphisternal joint.

Viewed from the side the profile of the diaphragm resembles an inverted J, the long limb extending up from the crura (upper lumbar vertebrae) and the short limb attached to the xiphisternum (level of T8 vertebra). Viewed from above the outline is kidney-shaped, in conformity with the oval outline of the body wall which is indented posteriorly by the vertebral column (Fig. 1.10, p. 19).

Trace the origin from behind. The **crura** are strong tendons attached to the bodies of the upper lumbar vertebrae at the lateral margins of their anterior convexities, alongside the psoas muscle. The large **right crus** is fixed to the upper three lumbar vertebrae and the discs between them, the smaller **left crus** to the upper two lumbar vertebrae and the intervening disc. Muscle fibres radiate from each crus, overlap, and pass vertically upwards before curving forwards into the central tendon. Some of the fibres on the abdominal surface of the **right crus** slope up to the **left** and surround the oesophageal orifice in a sling-like loop (Fig. 5.29, p. 333). Tendinous fibres from the medial edge of each crus unite with one another in front of the aorta at the level of T12 vertebra to form the **median arcuate ligament**. The **median arcuate ligament** is a thickening in the psoas fascia. It extends from the lower part of the body of L1 (or sometimes L2) vertebra to a ridge on the anterior surface of the transverse process of L1 vertebra, at the lateral margin of psoas. From this ridge the **lateral arcuate ligament** extends across to the twelfth rib at the lateral border of quadratus lumborum; it is a thickening in the anterior layer of the lumbar fascia. Muscle fibres arise alongside the

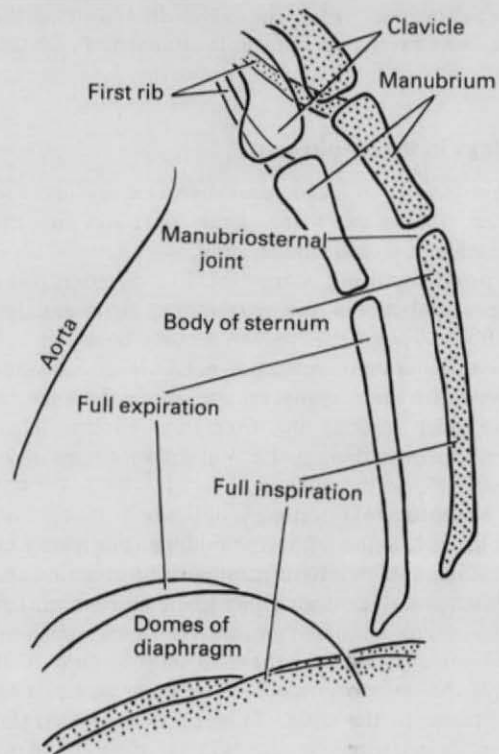


Fig. 4.6 Movements of the sternum and diaphragm during respiration. The outlines were traced from a lateral radiograph. In full expiration the manubriosternal angle measures 161° ; this changes to 154° in full inspiration.

crus from the medial and lateral arcuate ligaments (but not from the median). Further laterally a digitation comes from the tip of the twelfth rib, thence around the costal margin a digitation arises from each costal cartilage and adjacent rib up to the seventh. These muscular slips all arise from within the costal cartilages and ribs, interdigitating with the slips of origin of transversus abdominis. Finally, in front, the muscle sheet is completed by fibres that pass backwards from the xiphisternum to the central tendon. These are the shortest muscle fibres of the diaphragm; the longest fibres are those which arise from the ninth costal cartilage.

The **central tendon** is shaped like the club on a playing card. A rounded leaf, placed nearer the front than the back, is fused on each side with a similar leaf that extends back towards the paravertebral gutter. The tendon, consisting of interlaced fibres, is inseparable from the fibrous pericardium, with which it is embryologically identical. Near the junction of central and right leaves it is pierced by a foramen, the vena

caval opening, to which the adventitial wall of the inferior vena cava is very strongly attached (Fig. 5.29, p. 333).

Openings in the diaphragm

For the passage of structures between thorax and abdomen there are three large openings in the diaphragm and several smaller ones.

The **aortic opening** is opposite T12 vertebra. It is a midline arch between the overlapping right and left crural fibres, *behind* the median arcuate ligament and therefore *behind* the diaphragm, not *in* it. It transmits the aorta with the azygos vein to the right and the thoracic duct leading up from the cisterna chyli between them (although the vein or duct may make their own holes in the right crus).

The **oesophageal opening** is opposite T10 vertebra, usually an inch to the left of the midline (but it may be *in* the midline, its developmental position), behind the seventh left costal cartilage. It lies in the fibres of the left crus, but a sling of fibres from the *right* crus passes on the abdominal surface of these to loop around it. It transmits the oesophagus, which is firmly attached by fibrous tissue to the sling. This 'phreno-oesophageal ligament' is stretched in the 'sliding' type of hiatus hernia (p. 251). The vagal trunks and the oesophageal branches of the left gastric artery, with accompanying veins and lymphatics, perforate the fibrous tissue to accompany the oesophagus.

The **vena caval foramen** is opposite T8 vertebra just to the right of the midline, behind the sixth right costal cartilage and lies *in the central tendon*. The right phrenic nerve pierces the central tendon alongside the inferior vena cava at this opening (the two are separated in the mediastinum by the fibrous pericardium).

Other structures make their own smaller openings. The *hemiazygos vein* passes through the left crus. The *greater, lesser, and least splanchnic nerves* pierce each crus, the *sympathetic trunk* passes behind the medial arcuate ligament, the *subcostal nerve and vessels* pass behind the lateral arcuate ligament, while the *left phrenic nerve* pierces the muscle of the left dome. The *neurovascular bundles* of the seventh to the eleventh intercostal spaces pass between the digitations of the diaphragm and transversus abdominis into the neurovascular plane of the abdominal wall. The *superior epigastric vessels* pass between the xiphisternal and costal (seventh) fibres of the diaphragm. Finally extraperitoneal *lymph vessels* on the abdominal surface pass through the diaphragm to lymph nodes lying on its thoracic surface, mainly in the posterior mediastinum.

Blood supply

The costal margin of the diaphragm is supplied by the lower five intercostal and the subcostal arteries. The main mass of fibres rising up from the crura are supplied on their *abdominal* surface by right and left inferior phrenic arteries from the abdominal aorta (Fig. 5.29, p. 333). The tiny pericardiacophrenic artery, supplying the phrenic nerve and the pleura and the fibrous pericardium, is almost spent as it reaches the diaphragm.

Nerve supply

Each half of the diaphragm, including the crus, is supplied by its own phrenic nerve (C3, 4, 5 but predominantly C4, p. 261). The part of the *right* crus that lies to the *left* of the oesophageal opening is supplied by the *left* phrenic (because these muscle fibres are derived from left cervical myotomes). The lower intercostal nerves send some proprioceptive fibres to the periphery of the diaphragm but no motor fibres; the motor supply is solely from the phrenics. The right phrenic passes through the foramen for the inferior vena cava; the left pierces the muscular part in front of the central tendon and just to the left of the pericardium (p. 261). Reaching the abdominal surface of the diaphragm, both nerves divide into anterior, lateral and posterior branches which run radially giving off branches that enter the muscle from below to supply it with motor and sensory fibres. Incisions in the diaphragm are made either round the periphery or radially towards the site of entry of the main nerve to avoid cutting across the major branches.

Associated with a lifetime of constant activity, about 55% of diaphragmatic muscle fibres (and 65% of intercostal muscle fibres) are of the slow twitch variety.

Actions

The major role of the diaphragm is inspiratory, but it is used also in abdominal straining.

Inspiration. When the fibres contract in tranquil inspiration only the domes descend; this sucks down the lung bases and does not disturb the mediastinum. In a deeper breath further descent of the domes, below the level of the central tendon, can depress the central tendon from T8 to T9 level. This stretches the mediastinum (traction on pericardium and great vessels) and no further descent of the tendon is possible. Further contraction of the muscle (maximum inspiration) now everts the ribs of the costal margin in the 'bucket-handle' movement (Fig. 4.10 and below).

Note the beneficial effect on the three main openings. As the diaphragm contracts intra-abdominal pressure tends to rise, and the *vena caval foramen* (in the central tendon) is pulled widely open to assist venous return via the inferior vena cava. The *oesophageal opening* is held closed by the pinch-cock contraction of the muscle sling from the right crus, to discourage regurgitation of stomach contents. The *aortic opening* is unaffected because it is not within the diaphragm but behind it.

Hiccup (hiccough) is a (repeated) spasmodic contraction of the diaphragm, its contraction being followed immediately by closure of the glottis and subsequent release of the trapped air to produce the characteristic sound.

Expiration. Whether expiration is tranquil or forced (coughing, sneezing, blowing, etc.) the diaphragm is *wholly* passive, its relaxed fibres being elongated by pressure from below.

Abdominal straining. For evacuation of a pelvic effluent (defaecation, micturition, parturition) its contraction aids that of the abdominal wall in raising intra-abdominal pressure. It is much weaker than the powerful obliques, transversus and recti, so for maximum pressure a deep breath is held by a closed glottis, and the diaphragm is prevented from undue elevation by being pressed up against a cushion of compressed air. Forcible escape of some of this air causes the characteristic grunt.

During heavy lifting in the stooping position abdominal straining is beneficial. With the breath held and intracoelomic pressure raised as above, the vertebral column cannot easily flex; it is as though an inflated football filled the body from pelvic brim to thoracic inlet. The weight of the stooping trunk is supported on the football, freeing erector spinae to use all its power to lift the weight. Such acts are similarly accompanied on occasion by the characteristic grunt.

Development

The origins of the muscle fibres and connective tissue elements of the diaphragm are different. The connective tissue is derived from several sources: the *transverse septum*, which gives rise to most of the central tendon; the *oesophageal mesentery*, which forms the connective tissue round the oesophageal and vena caval openings; and from the *pleuroperitoneal membranes* and *mesoderm* of the dorsal body wall, which form the connective tissue of the periphery of the diaphragm. The parts that form the central tendon remain as connective tissue, but the rest becomes invaded through the transverse septum by muscle cells derived from the third, fourth and fifth

cervical myotomes. The muscle cells carry their own nerve supply with them, hence the motor supply from the phrenic nerves. At the junction of the lumbar and costal parts of the diaphragm (at the twelfth rib where the lateral arcuate ligament is attached), muscle fibres may be absent leaving only an area of connective tissue covered by pleura above and peritoneum below; this is the *lumbocostal trigone*. If the lumbar and costal elements fail to fuse at all, there will be a gap here — *Bochdalek's foramen*, a possible site for a congenital diaphragmatic hernia. This type of defect is commoner on the left, possibly because pressure from the liver on the right encourages earlier closure there, and a large defect present at birth may result in the stomach and other abdominal viscera herniating into the thoracic cavity. Another possible but smaller hernial site is at the junction of the costal and xiphoid origins — *Morgagni's foramen*.

Diaphragmatic hernia

The congenital types of diaphragmatic hernia have just been mentioned. Of the acquired varieties, the commonest is the *sliding* type of hiatus hernia, through the oesophageal opening. Here the phreno-oesophageal ligament becomes stretched so that the gastro-oesophageal junction rises up into the thorax. In the much rarer *gliding* or *paraesophageal* type, the phreno-oesophageal ligament is not stretched but a pouch of peritoneum, usually containing a pouch of stomach, projects upwards alongside the oesophagus.

THORACIC MOVEMENTS AND RESPIRATION

The main muscle actions in respiration can be summarized as follows. In quiet respiration, inspiration is due to the action of the diaphragm, the intercostal muscles adjacent to the sternum, and the scalene muscles. Sternocleidomastoid is an accessory muscle of inspiration, with the more lateral parts of the external intercostals assisting. The older teaching that the external intercostals were concerned with inspiration and the internal intercostals with expiration may have been a simple summary but is no longer tenable; modern investigations suggest that the intercostals are more important for twisting movements of the thorax than for respiration, though they probably help to prevent bulging of the interspaces. Expiration is largely passive but assisted by the oblique and transversus muscles of the abdominal wall and transversus thoracis. Erector spinae, quadratus lumborum (fixing the last rib), pectoralis major and latissimus dorsi can all assist in deep and forced inspiration.

All three diameters of the thorax — anteroposterior, transverse and vertical — are increased during inspiration. The anteroposterior diameter increases because the body of the sternum moves forward as the ribs are raised, and the sternal movement is facilitated by the hinge movement (up to about 7°) at the manubriosternal joint (Fig. 4.6). If this joint becomes ankylosed, thoracic expansion is virtually lost (as in emphysema) and only diaphragmatic respiration is possible. A typical upper rib is raised by movement along an axis that passes through the neck of the rib — the 'pump-handle' movement, with a rotation of the neck and a rotatory movement at the costotransverse joint (Fig. 4.7), for which purpose these joint surfaces in upper ribs are reciprocally *curved*. Lower ribs are elevated by movement along an axis that passes from the costochondral junction at the front to the joint of the head of the rib at the back — the 'bucket-handle' movement, as when lifting up the fallen handle from the side of a bucket (Fig. 4.8), for

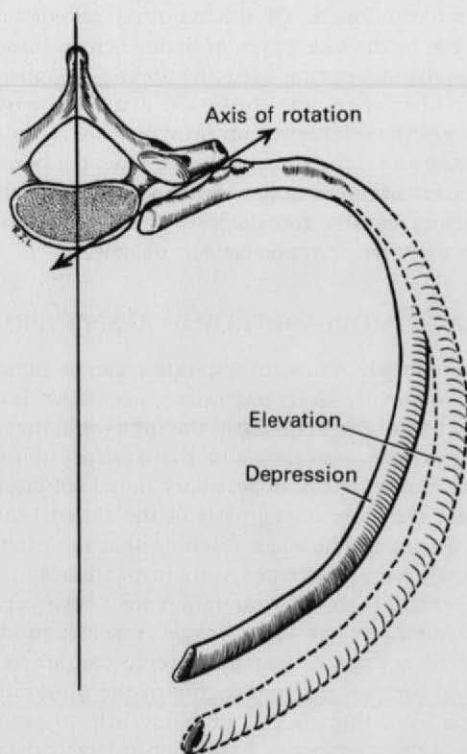


Fig. 4.7 Articulation of an upper rib and vertebra, showing the axis of rotation. Elevation increases the anteroposterior and transverse diameter of the thorax. Remember that the shaft of a rib slopes down at an angle of 45° ; this is not apparent from a diagram.

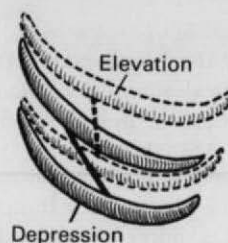


Fig. 4.8 Action of the external intercostal muscles in elevating ribs. The heavy outline represents two ribs connected by muscle fibres. The interrupted outline represents the two ribs when elevated. In spite of the fact that the two ribs are themselves farther apart, the muscle fibre is shorter because it now lies more nearly at a right angle between the ribs.

which purpose the surfaces of the costotransverse joints of lower ribs are *flat*, to allow a gliding movement. This increases the transverse diameter of the lower thorax. Change in the vertical extent of the thoracic cavity is due to diaphragmatic movement (Figs 4.9 and 4.10).



Fig. 4.9 Radiograph of the thorax in extreme expiration, in a healthy male aged 21 years.



Fig. 4.10 Radiograph of the same thorax as in Figure 4.9 taken in full inspiration. The anterior ends of the ribs are elevated and the lower ribs everted. The descent of the domes of the diaphragm is greater than that of the central tendon.

Movements of the abdominal wall

Since the volume of the abdominal cavity remains constant, the abdominal wall moves in accordance with changes in the thoracic cavity. Diaphragmatic inspiration and rib inspiration occur simultaneously, but each in itself produces opposite movements in the abdominal wall. In purely diaphragmatic breathing, with the ribs motionless, descent of the diaphragm is accompanied by passive protrusion of the relaxed abdominal wall; indeed no descent is possible without such protrusion. Ascent of the diaphragm is accompanied by retraction of the abdominal wall; indeed, it is the active contraction of the abdominal wall muscles that forces the relaxed diaphragm up. This to-and-fro movement of the abdominal wall is usually called 'abdominal respiration'. It consists of alternate contraction of the diaphragm and the anterior abdominal wall.

In 'thoracic respiration' the movements of the abdominal wall are purely passive. If the ribs are elevated the diaphragm is elevated with the up-going costal margin and the abdominal wall is sucked in. With

descent of the costal margin the abdominal wall moves forwards again.

'Thoracic' inspiration makes the upper abdominal wall hollow, 'abdominal' inspiration makes the wall protrude. The ordinary simultaneous rib and diaphragm movements can be so balanced that the abdominal wall does not move at all. Thus may respiration function quite well in tight corsets, plaster casts, etc. In children and many women thoracic movement is greater than diaphragmatic movement. In men diaphragmatic movement is greater, especially as the years go by.

Central control of respiration

A number of cell groups in the pons and medulla (mostly in the reticular formation) control the respiratory cycle. In the medulla bilateral groups of cells in the region of the nucleus of the tractus solitarius appear to function as an *inspiratory centre* which may be responsible for the rhythmicity of breathing (a kind of 'respiratory SA node'). Their axons pass down the spinal cord to the contralateral phrenic nerve neurons. Other bilateral groups in and near the nucleus ambiguus influence abdominal and intercostal muscles. There are also neurons in the pons which can modify the activity of the medullary centres; these include the *pneumotaxic centre* (situated near the superior cerebellar peduncle), which is believed to control the changeover from inspiration to expiration, and an ill-defined *apneustic centre* which is also concerned with the duration of these respiratory phases. The cerebral cortex, diencephalon and hypothalamus can also exert their influence on respiration, either via the above centres or more directly to the anterior horn cells innervating respiratory muscles. Afferent vagal fibres (with cell bodies in the inferior vagal ganglion) provide information about tension in lung tissues. Hypoxia is detected peripherally (not centrally) by chemoreceptors in the carotid and aortic bodies (pp. 256 and 438); the brain itself responds to changes in carbon dioxide, not oxygen.

Cardiopulmonary resuscitation

The cardinal features of cardiopulmonary resuscitation (CPR) are recalled by the letters **ABC: Airway, Breathing, Circulation**. In unconscious patients lying on the back, the commonest cause of airway obstruction is the tongue falling back to the posterior pharyngeal wall. Extending the head and neck and holding the mandible forwards helps the tongue to come forwards to restore the *airway* (provided it is clear of foreign bodies such as vomit). Mouth-to-mouth *breathing* (ventilation) while holding the patient's nose

shut is carried out to inflate the lungs. The restoration of blood circulation is considered on page 266.

Thoracotomy

Surgical access to thoracic structures involves some kind of thoracotomy. In the *anterolateral* or *posterolateral* type, skin and underlying muscles are incised along the line of the chosen rib (often fifth or sixth) so that the periosteum can be stripped off the upper half of the front and back of the rib (so keeping away from the intercostal nerve and vessels which run immediately below a rib). The periosteal bed of the rib can then be incised to enter the pleural cavity. The nerve to serratus anterior may have to be sacrificed when incising that muscle in order to give the necessary exposure.

In anterior thoracotomy, usually called *median sternotomy*, the whole length of the sternum is split vertically in the midline, the sternal origin of the diaphragm detached, and the tissues behind the sternum freed by blunt dissection. Damage to the pleural sacs must be avoided, remembering that the right pleura may extend a little to the left of the midline (p. 281).

In the combined *thoracoabdominal incision*, the line of approach is through the ninth intercostal space, removing part of the ninth costal cartilage at the costal margin and then incising the diaphragm, anterior abdominal wall and peritoneum. The diaphragm is incised near its periphery or radially towards the point of entry of the phrenic nerve, thus avoiding damage to the main branches of the nerve (p. 250).

PART 3 THORACIC CAVITY

The cavity of the thorax is completely filled laterally by the lungs, each lying in its pleural cavity. The space between the pleural cavities occupying the centre of the thoracic cavity is the **mediastinum**. It contains the heart and great blood vessels, the oesophagus, the trachea and its bifurcation, the thoracic duct and the phrenic and vagus nerves. It is a very mobile area, the lungs and heart being in rhythmic pulsation, and the oesophagus dilating with each bolus that passes down it. Hence there is but a minimum of loose connective tissue between the mobile structures. They lie in mutual contact, but the spaces between them can be readily distended by inflammatory fluid, neoplasm, etc.

These loose spaces of the mediastinum, moreover, connect freely with those of the neck. Mediastinitis is an ever-present danger in infective collections in the neck.

Divisions of the mediastinum

There is a plane of division to which the whole topography of the mediastinum can be related, namely a plane passing horizontally through the sternal angle (of Louis), i.e. the manubriosternal joint (Fig. 4.11). From the second costal cartilages, this plane passes backwards to the lower border of T4 vertebra. Above, between it and the thoracic inlet, lies the *superior mediastinum*. Below the plane, the *inferior mediastinum* is conveniently divided into three compartments by the fibrous pericardium — a part in front, the *anterior mediastinum*, a part behind, the *posterior mediastinum*, and the *middle mediastinum* in between containing the pericardium and heart together with the adjoining parts of the great vessels and lung roots. Note that the anterior and posterior mediastina are in direct continuity with the superior mediastinum; their separation from it is purely descriptive, not anatomical. The plane passes through the bifurcation of the trachea, the concavity of the arch of the aorta, and just above the bifurcation of the pulmonary trunk. On the plane the azygos vein enters the superior vena cava, and the thoracic duct reaches the left side of the oesophagus in its passage upwards from the abdomen. Also lying in the plane are the ligamentum arteriosum and the superficial and deep parts of the cardiac plexus.

The prevertebral and pretracheal fasciae (p. 423) extend from the neck into the superior mediastinum. The former is attached over T4 vertebra; the latter blends with the pericardium over the front upper part of the heart. Thus, neck infection in front of the pretracheal fascia is directed into the anterior mediastinum, while, if it is behind the prevertebral fascia, it is imprisoned in the superior mediastinum in front of the vertebral bodies (Fig. 4.11). Elsewhere in the neck infection is directed through the superior into the posterior mediastinum.

PART 4 SUPERIOR MEDIASTINUM

GENERAL TOPOGRAPHY

The essential point about the disposition of the great veins and arteries of the superior mediastinum is their

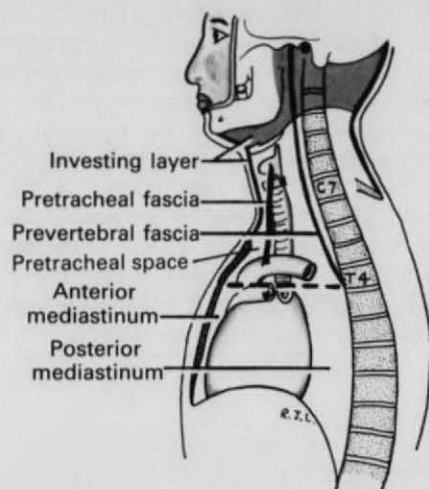


Fig. 4.11 Divisions of the mediastinum, showing the continuity with the tissue spaces of the neck. The superior mediastinum is above the interrupted line passing from the sternal angle to the lower border of T4 vertebra. The anterior mediastinum is continuous through the superior mediastinum with the pretracheal space of the neck, up to the hyoid bone. The posterior mediastinum is continuous with the retropharyngeal and paratracheal space of the neck, up to the base of the skull.

asymmetry. The veins are on the right, the arteries on the left. Structures themselves symmetrical, be they midline like the trachea, or bilateral like the apices of the lungs or the phrenic and vagus nerves, thus have asymmetrical relationships on the right and left sides. On the right side they are in contact with veins, on the left side with arteries. Veins expand enormously, large arteries not at all, during increased blood flow. Thus there is much 'dead space' on the right, none on the left, and it is into this space on the right side that tumours of the mediastinum or liquid collections tend to project.

The superior mediastinum is wedge-shaped (Fig. 4.11). The anterior boundary is the manubrium. The posterior boundary is much longer, due to the obliquity of the thoracic inlet. It consists of the bodies of the first four thoracic vertebrae; this wall is concave towards the mediastinum.

At the *thoracic inlet* (Figs 4.12 and 6.7A, p. 443, often called clinically the *thoracic outlet*) the oesophagus lies against the body of T1 vertebra. The trachea lies on the oesophagus and may touch the jugular notch of the manubrium. The midline of the inlet is thus wholly occupied by these two tubes. At the inlet the apices of the lungs lie laterally, separated by vessels and

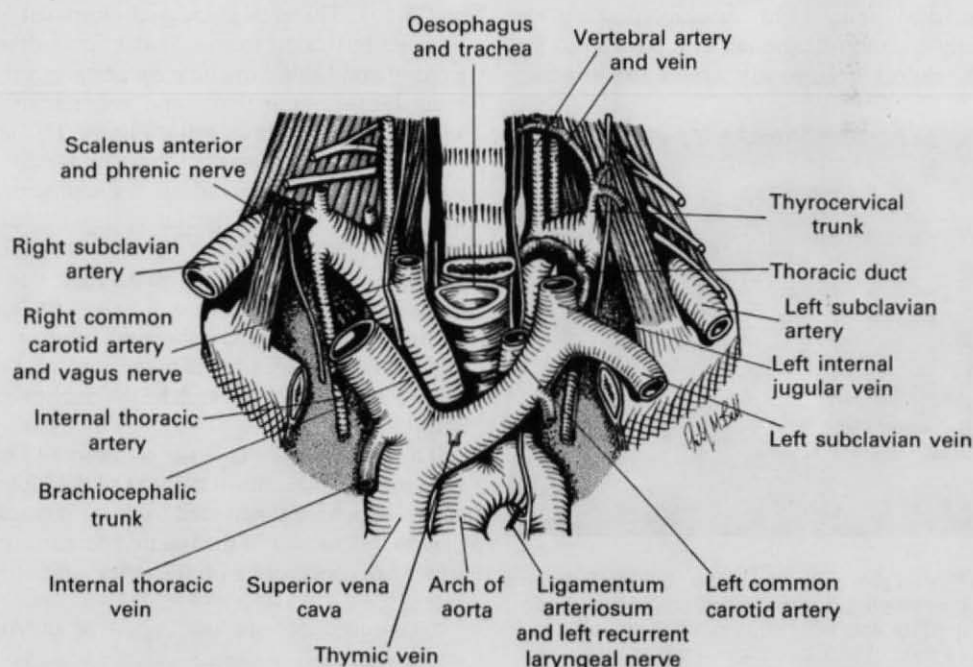


Fig. 4.12 Superior mediastinum and thoracic inlet, after removal of the sternum, costal cartilages and clavicles. The left brachiocephalic vein crosses in front of the three great arteries to join its fellow to form the superior vena cava.

nerves passing between the superior mediastinum and the neck. The concavity of the arch of the aorta lies in the plane of the sternal angle, i.e. the arch of the aorta lies *wholly in the superior mediastinum, behind the manubrium*. It does not pass from right to left, but from in front at the manubrium *backwards* to the body of T4 vertebra. It arches over the beginning of the left bronchus and the bifurcation of the pulmonary trunk (Fig. 4.16). The brachiocephalic trunk begins as a midline branch from the arch and immediately diverges to the right beside the trachea. The two other branches of the arch, the left common carotid and left subclavian arteries, pass upwards on the left side of the trachea, so that the thoracic part of the trachea is clasped by an asymmetrical V (Figs 4.12 and 4.13). These great arteries keep the left vagus nerve and apex of the left lung away from contact with the trachea. On the right side there is no structure to separate the trachea from the right vagus and apex of the right lung. Tracheal breath sounds are thus conducted, by direct contact, to the right apex. On the left side the great arteries intervene, and breath sounds are here more subdued, being conducted only along the bronchial tree.

The veins entering the superior mediastinum are the right and left brachiocephalic veins, each formed by the confluence of the internal jugular with the subclavian vein. They lie in front of the arteries and are asymmetrical. The right brachiocephalic vein runs vertically downwards; the left vein passes, on the other hand, almost horizontally across the superior

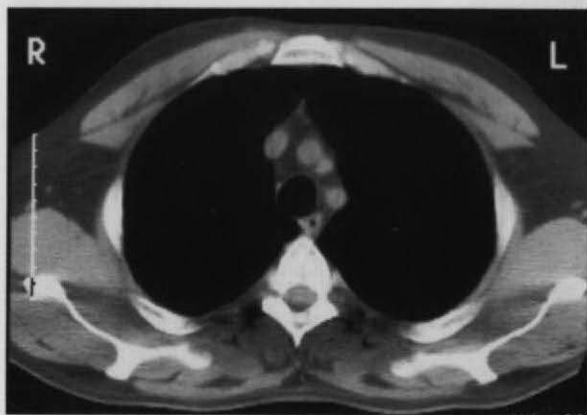


Fig. 4.13 CT scan above the level of the aortic arch. Viewed from below, the oesophagus with a rather small round lumen is seen in front of the vertebral column, and the round translucency in front of the oesophagus is the trachea. The four opacities adjacent to the trachea are, from the right side of the body to the left, the superior vena cava, brachiocephalic trunk, left common carotid artery and left subclavian artery.

mediastinum to join the right (Fig. 4.12). The confluence of the brachiocephalic veins produces the superior vena cava, which passes vertically downwards behind the right edge of the sternum, anterior to the right bronchus. Note that on the right side of the mediastinum the venous channels open into the right atrium, which forms the right border of the heart (Fig. 4.14). On the left side there are arterial channels, which are continuous with the left side of the heart, i.e. the right and left ventricles (Fig. 4.15). The phrenic nerves have, therefore, different relationships, the right to venous and the left to arterial structures.

GREAT VESSELS

Arch of the aorta

Emerging from the pericardium the ascending aorta approaches the manubrium and then at the level of the manubriosternal joint becomes the arch which passes backwards over the left bronchus (Fig. 4.16) to reach the body of T4 vertebra just to the left of the midline. From its upper convexity, which reaches as high as the midpoint of the manubrium — a convenient surface marking — arise the three great arteries for the head and upper limbs: the brachiocephalic trunk, and the left common carotid and left subclavian arteries (Figs 4.13 and 4.15). The arch is crossed on its left side by the phrenic and vagus nerves as they pass downwards in front of and behind the lung root respectively. Between them lie the sympathetic and vagus branches to the superficial part of the cardiac plexus. The left superior intercostal vein passes forwards across the arch superficial to the vagus, deep to the phrenic, to empty into the left brachiocephalic vein. The left recurrent laryngeal nerve hooks around the ligamentum arteriosum to pass upwards on the right side of the arch of the aorta, in the groove between the trachea and oesophagus. The pulmonary trunk bifurcates into right and left pulmonary arteries in the concavity of the arch. On the right side of the arch lie the trachea and oesophagus.

The adventitial layer of the arch contains *baroreceptors* (like the carotid sinus in the wall of the internal carotid artery — p. 438) innervated by vagal nerve fibres which pass to the nucleus of the tractus solitarius (p. 616) and which are concerned with the reflex control of the heart rate.

Under the arch in the region of the ligamentum arteriosum there are some very small masses of tissue, the *aortic bodies* (supplied by vagal fibres), which like the carotid bodies (p. 438) are concerned with respiratory reflexes, detecting hypoxia (p. 253).

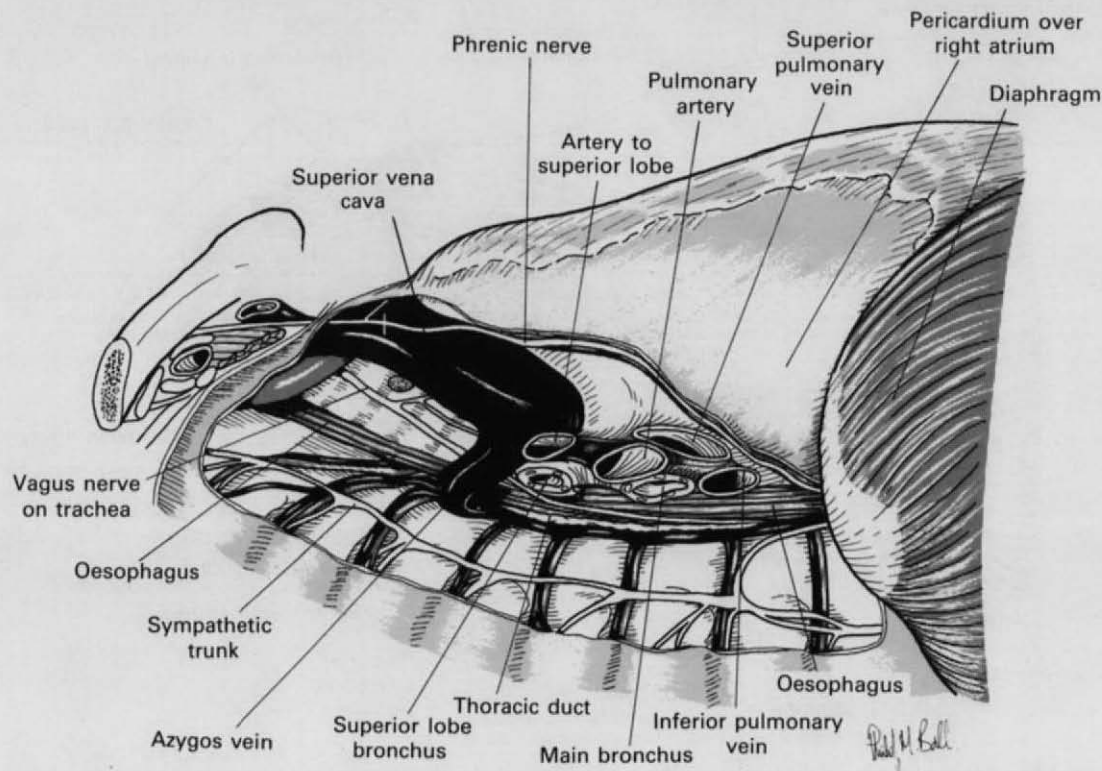


Fig. 4.14 Mediastinum from the right. Above the lung root and the azygos vein the right vagus nerve runs obliquely downwards and backwards across the side of the trachea. The right phrenic nerve passes down over venous structures. In the lung root the artery and bronchus to the upper lobe lie above the main bronchus and pulmonary artery; the superior pulmonary vein is anterior to the artery and the inferior pulmonary vein is the lowest structure in the root.

The **brachiocephalic trunk** arises in or a little to the left of the midline of the body. It slopes upwards across the trachea to the back of the right sternoclavicular joint, where it divides into the right common carotid and right subclavian arteries. It has no branches apart from the rare thyroidea ima artery, which may arise from it or directly from the arch of the aorta. The termination of the left brachiocephalic vein lies in front of the artery (Fig. 4.12). The trachea is immediately behind the jugular notch at the thoracic inlet, but it slopes back and the manubrium slopes forward below this, and the brachiocephalic trunk and left brachiocephalic vein occupy the space thus provided (Fig. 4.12).

The **left common carotid artery** arises just behind the brachiocephalic trunk from the upper convexity of the aortic arch. It passes straight up alongside the trachea into the neck (Fig. 4.15). It has no branches in the mediastinum.

The **left subclavian artery** arises just behind the left common carotid; the two run upwards together. The subclavian artery arches to the left over the apex of the lung, which it deeply grooves. It leaves the left common carotid at a point directly behind the left sternoclavicular joint. It has no branches in the mediastinum.

Ligamentum arteriosum

This is the shrivelled fibrous remnant of the ductus arteriosus of the fetus, a channel that short-circuited the lungs. It passes from the very commencement of the left pulmonary artery to the concavity of the aortic arch (Fig. 4.12), beyond the point where the left subclavian artery branches off. It lies almost horizontally. The left recurrent laryngeal nerve hooks around it. The superficial part of the cardiac plexus lies anterior to it, and the deep part on its right, in front of the left main bronchus.

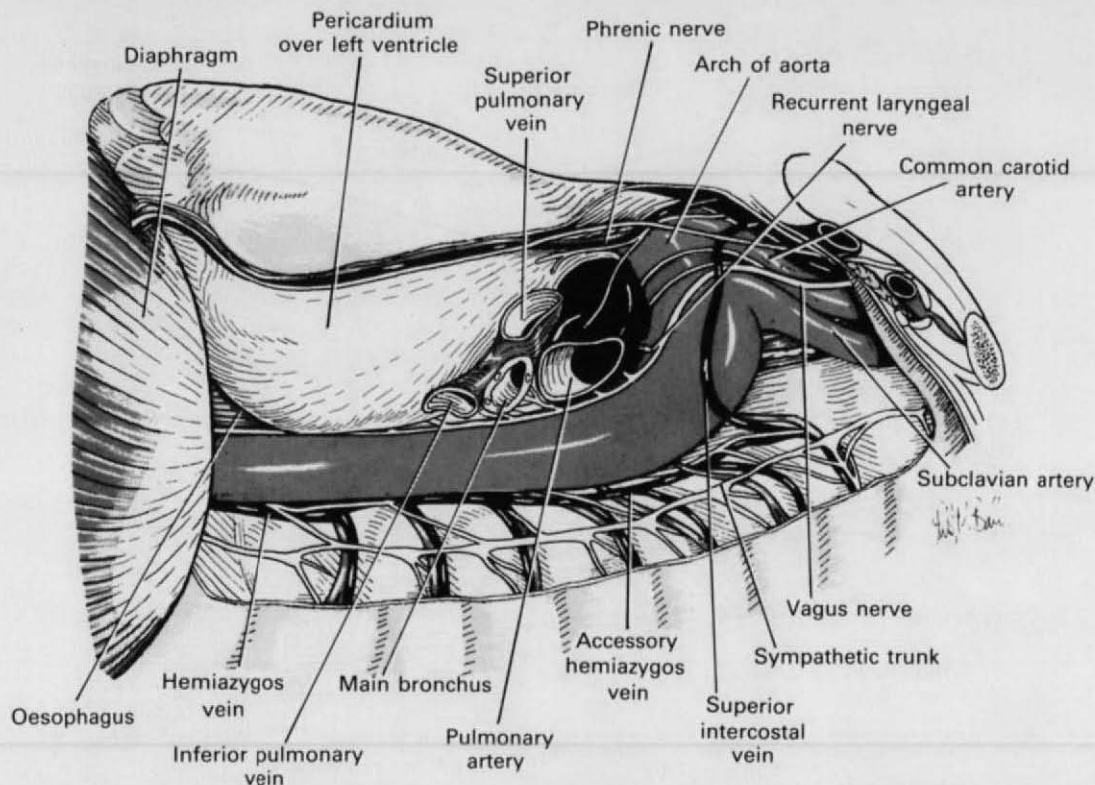


Fig. 4.15 Mediastinum from the left. Above the lung root and the arch of the aorta the left vagus and phrenic nerves are held away from the trachea and oesophagus by the common carotid and subclavian arteries. The phrenic nerve passes down over arterial structures. In the lung root the superior pulmonary vein is the most anterior structure, with the pulmonary artery above and the main bronchus behind; the inferior pulmonary vein is the lowest structure in the root.

Surgical approach. The pleura over the aortic arch is incised behind the vagus nerve and upwards towards the origin of the left subclavian artery. The pleural flap is reflected forwards with the vagus and its left recurrent laryngeal branch to give sufficient access to the ductus.

Brachiocephalic veins

The **brachiocephalic veins** (formerly called innominate) are formed behind the sternoclavicular joints by confluence of the internal jugular and subclavian veins. In the neck each internal jugular vein lies lateral to the common carotid artery, in front of scalenus anterior. The subclavian vein, running medially into the brachiocephalic, lies lateral to and then below the muscle. Medial to scalenus anterior, in front of the first part of the subclavian artery, the vein has been joined by the internal jugular vein and is thence called the brachiocephalic. This part of each brachiocephalic vein

receives tributaries corresponding to the branches of the first part of the subclavian artery (vertebral, inferior thyroid, internal thoracic and, on the left side only, superior intercostal).

The **right brachiocephalic vein** commences behind the right sternoclavicular joint and runs vertically downwards; it is a persistent part of the right anterior cardinal vein of the embryo. It receives the right lymphatic duct and right jugular and subclavian lymph trunks, which normally enter independently of each other.

The **left brachiocephalic vein** passes almost horizontally behind the upper half of the manubrium across the superior mediastinum to join the right vein at the lower border of the first right costal cartilage (Fig. 4.12). It is a persistent anastomotic channel between the two anterior cardinal veins of the embryo (p. 45). In the infant the left brachiocephalic vein projects slightly above the jugular notch, and may do so in the adult if the vein is distended, especially if the

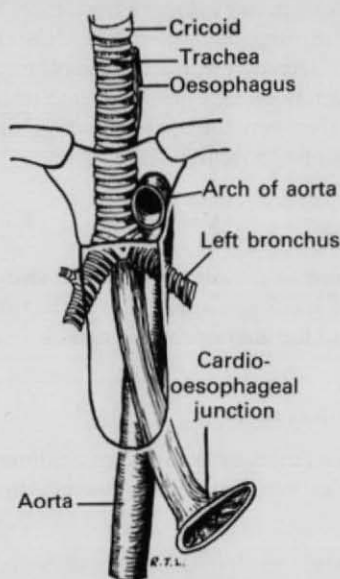


Fig. 4.16 Surface projection of the trachea, oesophagus and aorta. The arch of the aorta lies in an anteroposterior plane, looping over the left main bronchus.

head and neck are thrown back. The vein is then vulnerable to suprasternal incisions (e.g. tracheotomy). The commencement of the vein receives the thoracic duct, which often divides into two or three branches that join the vein separately. In addition to the vertebral and internal thoracic veins the left brachiocephalic vein receives most of the blood from the inferior thyroid plexus of veins. The left superior intercostal vein joins it near the midline of the body (Fig. 4.15), and a large thymic vein commonly enters nearby.

The thymus or its remnants and the pretracheal fascia lie in front of the vein. The fascia directs a retrosternal goitre into the space between the vein and the brachiocephalic trunk and trachea.

Superior vena cava

This vessel commences at the lower border of the first right costal cartilage by confluence of the two brachiocephalic veins (Figs 4.12 and 4.14). It passes vertically downwards behind the right border of the sternum and, piercing the pericardium at the level of the second costal cartilage enters the upper border of the right atrium at the lower border of the third right costal cartilage. These cartilages thus form the *surface markings* for the vessel. Behind the sternal angle, opposite the second right costal cartilage, it receives the azygos vein,

which has arched forwards over the root of the right lung. Developmentally, the superior vena cava is formed as the persisting right anterior cardinal vein, but below the entrance of the azygos vein it represents the persisting right common cardinal vein (duct of Cuvier) of the embryo (p. 45).

Cardiac plexus

The **cardiac plexus** consists of various sympathetic, parasympathetic and afferent fibres and is divided into superficial and deep parts, but this is merely a descriptive division and functionally they are one. Their branches enter the pericardium to accompany the coronary arteries (vasomotor) and also to reach the SA node (cardioinhibitor and cardioaccelerator), the AV node and bundle and the ventricular myocardium. These branches form the *coronary* and *cardiac parts* of the plexus. Other branches enter the lung root as the *pulmonary part* (*pulmonary plexus*) for the supply of bronchial muscle and the blood vessels of the lung.

The **superficial part** of the cardiac plexus is formed by the union of the inferior cervical cardiac branch of the left vagus and the cardiac branch of the left cervical sympathetic ganglion, i.e. by the two small autonomic nerves which cross the left side of the arch of the aorta between the phrenic and vagus nerves (p. 256). This part lies in front of the ligamentum arteriosum and becomes continuous with the deep part.

The **deep part** of the cardiac plexus is larger and receives contributions from the right vagus nerve by its upper and lower cervical cardiac branches, from the left vagus by its superior cervical cardiac branch, and a branch from each recurrent laryngeal nerve, and also sympathetic fibres from the remaining five cervical sympathetic ganglia (the middle and inferior on the left and all three on the right), and from the upper five or six thoracic sympathetic ganglia of both sides. This part lies to the right of the ligamentum arteriosum, in front of the left bronchus at the bifurcation of the pulmonary trunk. The sympathetic fibres are postganglionic from cell bodies in the cervical and upper thoracic ganglia, and the preganglionic cells are in the lateral horn of the upper five or six thoracic segments of the cord. The vagal fibres are preganglionic from cell bodies in the dorsal motor nucleus of the vagus but some are apparently intermingled with cells of the nucleus ambiguus. The vagal fibres relay in the heart wall, not in the cardiac plexus.

The vagi contain afferent fibres concerned with cardiovascular reflexes, and their cell bodies are in the inferior vagal ganglia. Pain fibres run with sympathetic nerves, reaching any of the three cervical and upper two

or three thoracic sympathetic ganglia, but most go to the inferior cervical and first thoracic ganglia. The pain fibres pursue the usual pathway to the central nervous system, passing through the sympathetic ganglia to the spinal nerves via white rami communicantes (Fig. 1.22C) (hence upper thoracic sympathectomy for the relief of cardiac pain); their cell bodies are in the posterior root ganglia. The connexion with cervical and thoracic spinal nerves presumably explains the referral of cardiac pain to the arm, chest or neck. Myocardial infarction may destroy afferent fibres, including those subserving pain.

TRACHEA

The **trachea** is the continuation of the larynx and commences in the neck below the cricoid cartilage at the level of C6 vertebra, 5 cm above the jugular notch. Entering the thoracic inlet in the midline (Fig. 4.12) it passes downwards and backwards behind the manubrium to bifurcate into the two principal or main bronchi (p. 284) on a level just below the lower border of the manubrium (Fig. 4.16). This is true of the recumbent cadaver, in whom the trachea is about 10 cm long and 2 cm in diameter; in the living the bifurcation may be 5 cm lower in full inspiration. The cricoid cartilage and sternal angle provide easy *surface markings* for the upper and lower ends of the trachea.

The **cervical part** of the trachea is described on page 433.

The **thoracic part** runs through the superior mediastinum in front of the oesophagus (Figs 4.12 and 4.16) to the upper part of the posterior mediastinum. In front of this part are the manubrium with sternohyoid and sternothyroid attached on each side, the inferior thyroid and left brachiocephalic veins and the remains of the thymus. The brachiocephalic and left common carotid arteries diverge on either side. The right side of the trachea is separated from the lung by the pleura which plasters the vagus nerve against the side of the tracheal wall (Fig. 4.14), and the arch of the azygos vein hooks forwards over the right bronchus. The right brachiocephalic vein and superior vena cava are anterolateral to the trachea. On the left the left common carotid and subclavian arteries (Fig. 4.15) prevent the pleura from coming into contact with the trachea as it does on the right, and the arch of the aorta hooks backwards over the left bronchus, with the left recurrent laryngeal nerve passing upwards in the groove between trachea and oesophagus.

The pulmonary trunk branches into the right and

left pulmonary arteries rather to the left of the tracheal bifurcation, in front of the left bronchus (Fig. 4.31). Here lies the deep part of the cardiac plexus. The right pulmonary artery crosses just below the tracheal bifurcation, and between the two is part of the tracheo-bronchial group of lymph nodes.

Blood supply

Branches from the inferior thyroid and bronchial arteries form anastomotic networks in the tracheal wall. Veins drain to the inferior thyroid plexus.

Lymph drainage

Lymphatic channels pass to the posteroinferior group of deep cervical nodes and to paratracheal nodes.

Nerve supply

The mucous membrane is supplied by afferent (including pain) fibres from the vagi and recurrent laryngeal nerves, which also provide parasympathetic fibres of uncertain function. Sympathetic fibres from upper ganglia of the sympathetic trunks supply the smooth muscle and blood vessels.

Structure

The patency of the trachea as an airway, its essential function, is maintained by 15–20 horseshoe-shaped hyaline cartilages (commonly called *tracheal rings* although they are never complete circles). The gaps in the rings are at the back, where there is smooth muscle, mostly transversely placed (the *trachealis* muscle), which here supplements the fibrous tissue of the rest of the framework. There is a high content of elastic fibres, to facilitate the necessary elastic recoil during respiration and neck movements. (In transection injury, as by the steering wheel in severe motor vehicle accidents, the distal cut end may disappear into the mediastinum due to this elasticity). The mucous membrane is of typical respiratory type, with pseudostratified columnar ciliated epithelium and goblet cells, mucous glands and scattered lymphoid nodules.

For development see page 40.

Function

The cartilaginous rings keep the airway open, mucus traps particles, cilia beat upwards to clear debris, and

glandular secretion helps to humidify the passing air. During swallowing the trachea is stretched as the larynx moves upwards (the bifurcation does not move) and elasticity restores the normal position. Sudden descent of the diaphragm pulling on the bifurcation, pericardium and aortic arch produces the clinical sign of 'tracheal tug'. The trachealis muscle controls the diameter of the tube. During coughing there is a 30% increase in transverse diameter produced by compressed air in the trachea while the vocal cords are shut, but 10% narrowing of the resting diameter at the instant the cords open. Like the choke barrel of a shotgun this greatly increases the explosive force of the blast of compressed air.

PHRENIC AND VAGUS NERVES

Phrenic nerve

Arising principally from C4 in the neck, the nerve passes down over the anterior scalene muscle across the dome of the pleura behind the subclavian vein. It runs through the mediastinum in front of the lung root. Each nerve lies in the thorax *as far lateral as possible*, being in contact laterally with the mediastinal pleura throughout the whole of its course. Their medial relations, however, are asymmetrical. The **right phrenic nerve** is in contact with venous structures throughout the whole of its course (Fig. 4.14). The right brachiocephalic vein, the superior vena cava, then the right atrium, and the inferior vena cava, lie to its medial side. It reaches the under surface of the diaphragm by passing through the vena caval foramen in the central tendon.

The **left phrenic nerve** (Fig. 4.15) has the left common carotid and left subclavian arteries that arise from the arch of the aorta to its medial side. It crosses the arch lateral to the superior intercostal vein and in front of the vagus nerve, and then runs laterally down the pericardium over the left ventricle towards the apex of the heart. It reaches the under surface of the diaphragm by piercing the muscular part just to the left of the pericardium. Note that the left phrenic passes through diaphragmatic muscle but the right through tendon.

On the under surface of the diaphragm each phrenic nerve splits into three main branches — *anterior, lateral and posterior* — which radiate from the point of entry, giving off branches as they go. Each nerve is the *sole motor supply* to its own half of the diaphragm, including the crus. The part of the right crus that lies to the left of the oesophagus is supplied by the left phrenic (because these fibres are embryologically left-sided). About two-

thirds of the phrenic nerve fibres are motor; the rest are sensory to the diaphragm (except for the most peripheral parts which receive intercostal afferent fibres), and to the mediastinal pleura, the fibrous pericardium, the parietal layer of serous pericardium, and the central parts of the diaphragmatic pleura and peritoneum. The nerve also gives branches to the areolar tissue of the mediastinum but not to viscera; in a word, it is the nerve of the transverse septum. The nerve is supplied with blood by the pericardiophrenic artery (a branch of the internal thoracic) which accompanies it, with companion veins, all the way to the diaphragm. To avoid damage to the nerve supply, incisions in the diaphragm are made as far as possible round the periphery or radiating towards the main nerve entry point.

Pain referred from the diaphragmatic peritoneum (C4) is classically felt in the shoulder tip (C4), but pain from thoracic surfaces supplied by the phrenic nerve (pleura, pericardium) is usually located there, albeit vaguely.

Vagus nerve

In their descent through the thorax the **vagus nerves** are, so to speak, *attempting to reach the midline* at all levels. Thus the **right vagus** (Fig. 4.14) is in contact with the trachea, while the **left** (Fig. 4.15) is held away from that structure by the great arteries that spring from the arch of the aorta. The left nerve crosses the arch *deep* to the left superior intercostal vein, and the right nerve lies on the trachea deep to the arch of the azygos vein. Each vagus passes down behind the lung root, here giving off a large contribution to the pulmonary plexuses. The nerves now pass onwards to achieve their object of reaching the midline by entering into the oesophageal plexuses on the surfaces of the lower oesophagus. In the plexuses they become mixed, and the right and left vagal trunks, as they leave the plexuses, contain fibres from each vagus (p. 278). On the arch of the aorta the left vagus nerve *flattens out* and gives off its **recurrent laryngeal branch** (Fig. 4.15). This nerve hooks around the ligamentum arteriosum, and, passing up on the right side of the aortic arch, ascends in the groove between trachea and oesophagus. The right recurrent laryngeal nerve is given off in the root of the neck and hooks around the right subclavian artery (Fig. 4.12). From the right vagus nerve thoracic cardiac branches enter the deep part of the cardiac plexus, as do cardiac branches from both recurrent laryngeal nerves. Both the recurrent laryngeal nerves supply the whole trachea and the adjacent oesophagus (i.e. above the lung roots) but are of supreme importance because of their supply to muscles of the

larynx (p. 504) and relation to the thyroid gland (p. 431).

The *oesophagus* lies against the vertebrae at the back of the superior mediastinum. The *thoracic duct* lies on its left side. Both structures pass through the posterior mediastinum; they are described on pages 277 and 279.

PART 5 ANTERIOR MEDIASTINUM

This space, little more than a potential one, lies between the pericardium and sternum. It is overlapped by the anterior edges of both lungs. It is continuous through the superior mediastinum with the pretracheal space of the neck. Its principal content is the thymus, which may lie, however, only in the anterior part of the superior mediastinum.

THYMUS

The **thymus** may appear to be a single organ, but in

fact it consists of right and left lobes closely applied to each other for much of their extent (Fig. 4.17). It is usually most prominent in children, where it may be expected to extend from the level of the fourth costal cartilages to the lower poles of the thyroid gland. In front of it lie the pretracheal fascia, the sternohyoid and sternothyroid muscles, the manubrium and upper part of the body of the sternum and their adjacent costal cartilages. The lobes are overlapped on each side by the pleura, to which the pretracheal fascia is firmly attached. Behind it are the pericardium, the arch of the aorta with its three large branches (brachiocephalic, left common carotid and left subclavian), the left brachiocephalic vein and the trachea.

The thymus can be distinguished from fat by being slightly different in colour (pinker or browner in life), with lobules that are larger, smoother and denser than fat. The structure of the thymus is referred to on page 16.

Blood supply

Small branches enter the thymus from the inferior thyroid and internal thoracic arteries, and there are

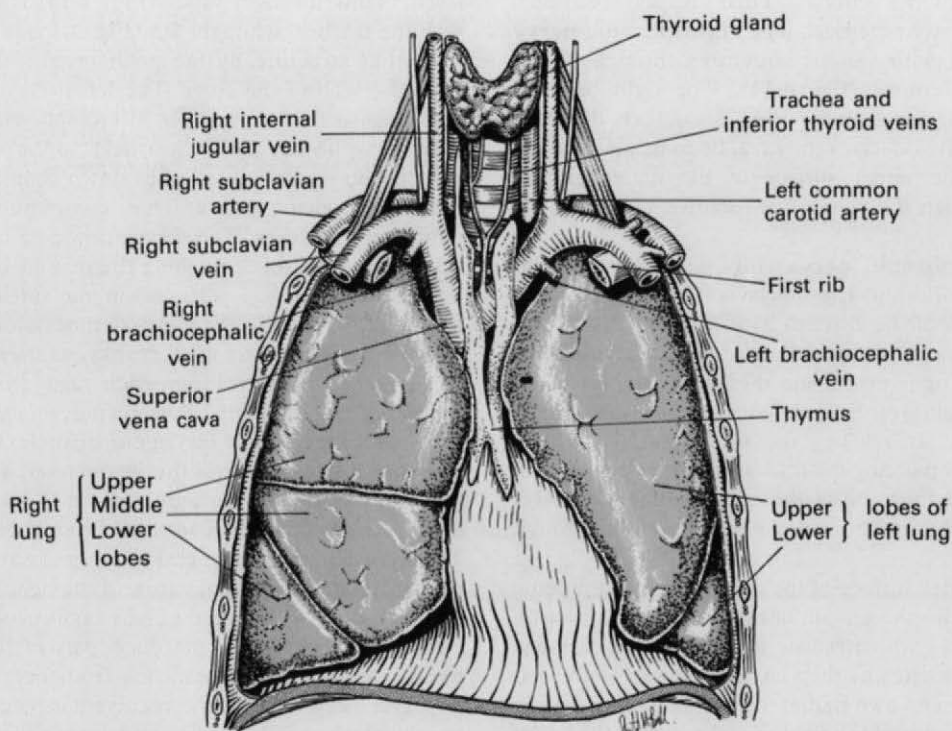


Fig. 4.17 Thoracic contents, seen after removal of the anterior thoracic wall. The thymus lies in front of the upper pericardium and great vessels.

corresponding veins. Frequently a rather large thymic vein formed by tributaries from both lobes enters the left brachiocephalic vein (Fig. 4.12).

Lymph drainage

Channels drain into parasternal, tracheobronchial and brachiocephalic nodes, but the thymus does not receive any afferent lymphatics.

Nerve supply

Sympathetic fibres entering with blood vessels are presumably vasomotor, and there are vagal fibres, but the roles of nerves and of the various neuroendocrine substances that have also been described in the thymus have not yet been clarified.

Development

The epithelium of the human thymus is believed to develop from the endoderm of the ventral part of the third and probably the fourth branchial pouches of both sides (hence the bilobed structure) and also from ectoderm of the corresponding branchial clefts. Some of the epithelial cells become the thymic (Hassall's) corpuscles; others form a network of epithelial reticular cells believed to be the source of thymic hormones concerned with the differentiation of T lymphocytes. Connective tissue elements are derived from surrounding mesoderm, but the original colonizing lymphocytes have migrated from the bone marrow. The developing thymus descends from the neck into the mediastinum in front of all the major contents. Although it regresses after puberty, the secretion of thymic hormones and its influence on lymphocytes that migrate to it continues throughout life.

Surgical approach

Exposure is usually through a median sternotomy. The pretracheal fascia is the guide to the thymus, for this thin layer must be exposed by clearing away the overlying fatty tissue and then incised so that the lobes can be dissected away from the posterior surface of the fascia. Thin-walled veins and the pleura are hazards, and although more laterally placed the phrenic nerves may be at risk when clearing extrapleural fat.

PART 6

MIDDLE MEDIASTINUM AND HEART

The term middle mediastinum (like inferior mediastinum) is not frequently used. It contains the pericardium and heart (described here), the adjoining parts of the great vessels (p. 267 and 271), the lung roots (p. 283) and parts of the phrenic nerves (p. 261) that pass down between pericardium and pleura.

PERICARDIUM

Do not confuse the *fibrous* pericardium with the *serous* pericardium. They are separate entities, with separate functions (p. 265).

Fibrous pericardium

This fibrous sac encloses the heart and also the roots of the great vessels, fusing with all of the vessels except the inferior vena cava (already fused with the tendon of the diaphragm). Its broad base overlies the central tendon of the diaphragm, with which it is inseparably blended. Both it and the central tendon are derived from the septum transversum, and can be regarded as one structure. The fibrous sac is connected to the upper and lower ends of the sternum by weak *sternopericardial ligaments*. It is supplied with blood by the pericardiophrenic and internal thoracic arteries.

Serous pericardium

A layer of serosa lines the fibrous pericardium, whence it is reflected around the roots of the great vessels to cover the entire surface of the heart. Between these parietal and visceral layers there are two sinuses: the transverse sinus and the oblique sinus of the pericardium. In order to understand the presence of these two spaces, it is desirable to recall the early development of the heart (p. 44). The heart first appears as a vascular tube lying free in a space, the *pericardial cavity*, within the transverse septum. The heart tube is suspended from the dorsal wall of this cavity by a *dorsal mesocardium*, a simple 'mesentery' consisting of two layers of serous pericardium reflected around the tube from the lining of the cavity (Fig. 4.18A). The arterial and venous ends of the tube are thus each surrounded by a simple sleeve of visceral pericardium. No matter how many vessels may be derived from either end of this tube, they must all

continue to be enclosed together in this single tube of serous pericardium. In fact, the arterial end splits into two, the aorta and the pulmonary trunk, while the venous end splits into six veins, the four pulmonary veins and the superior and inferior venae cavae. With elongation, bending and rotation of the heart tube

(Fig. 4.18C), the two arteries and the six veins pierce the adult pericardium in a pattern that can best be appreciated by study of the interior of the pericardium after the heart has been removed (Fig. 4.18D). It will be seen that the **oblique sinus** of the pericardium is no more than a cul-de-sac between the two left and

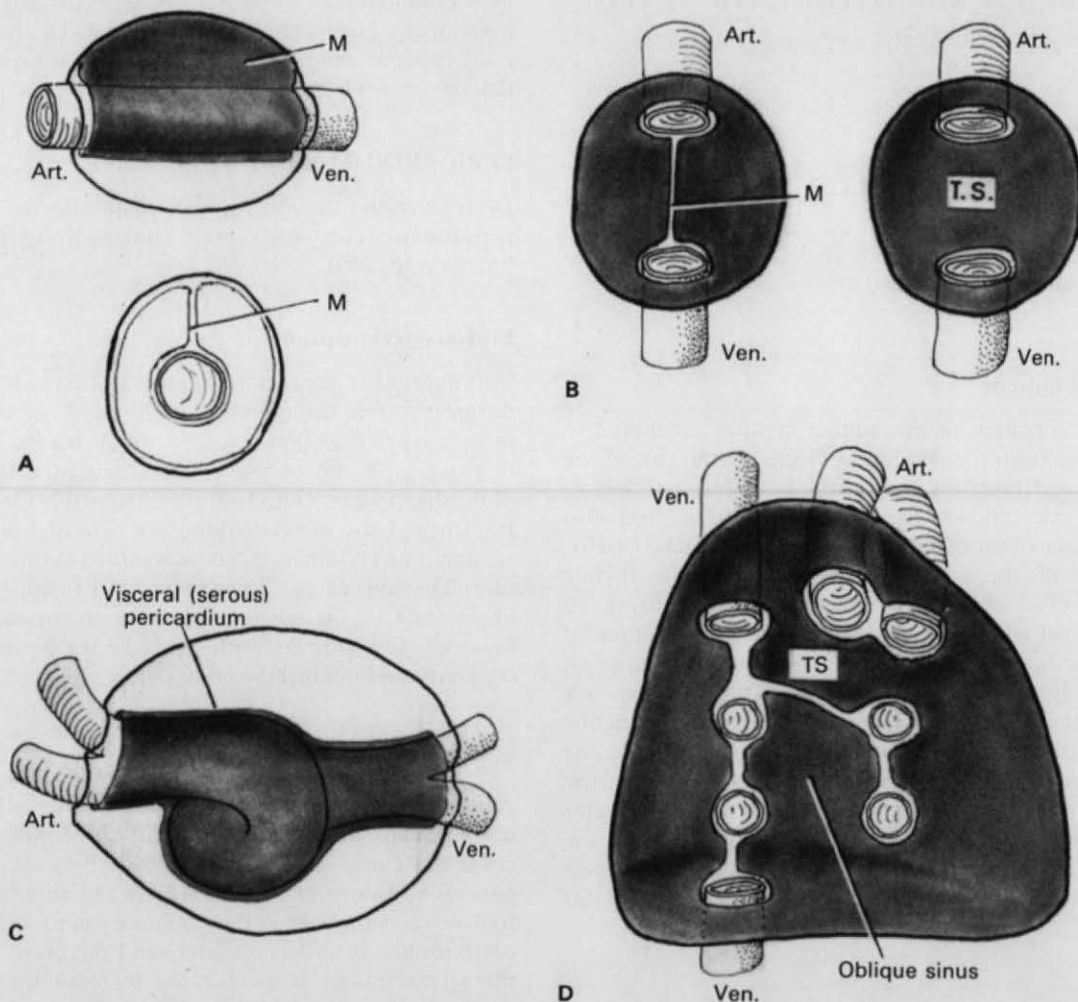


Fig. 4.18 Development of the sinuses of the serous pericardium.

A The simple heart tube suspended in the fibrous pericardium by the serous dorsal mesocardium (M), with the arterial and venous ends indicated (Art. and Ven.).

B Ventral view after removal of the heart tube. The left figure shows the dorsal mesocardium still present; in the right figure it has been absorbed, so giving rise to the space called the transverse sinus (TS). Each end of the heart tube remains surrounded by a single sleeve of serous pericardium.

C The heart tube elongates and rotates after the absorption of the dorsal mesocardium (lateral view). At each end of the tube the vessels are still surrounded by the same single sleeve of pericardium as in **B**.

D Ventral view of the adult pericardium after removal of the heart. The arterial and venous vessels are still surrounded by their single sleeves of serous pericardium with the transverse sinus between them; the aorta and pulmonary trunk are within one sleeve, and the two venae cavae and four pulmonary veins in the other. The oblique sinus is simply a cul-de-sac resulting from the wide separation of the four pulmonary veins.

two right pulmonary veins and the inferior vena cava. Its anterior wall is formed by the posterior wall of the left atrium, between the four pulmonary veins. The presence of the **transverse sinus** is due to the fact that the dorsal mesocardium breaks down, thus producing a communication from right to left and dorsal to the heart tube, between its arterial and venous ends (Fig. 4.18B). The transverse and oblique sinuses are separated from each other by a double fold of serous pericardium. A finger in the transverse sinus will pass across the pericardial cavity behind both aorta and pulmonary trunk, but in front of the superior vena cava on the right side, and the left auricle on the left. It is through the transverse sinus that a temporary ligature is passed to occlude pulmonary trunk and aorta during pulmonary embolectomy and other cardiac operations.

Nerve supply

The fibrous pericardium is supplied by the phrenic nerve. The parietal layer of serous pericardium that lines it is similarly innervated, but the visceral layer on the heart surface is insensitive. Pain from the heart (angina) originates in the muscle or the vessels and is transmitted by sympathetic nerves (p. 259). The pain of pericarditis originates in the parietal layer only, and is transmitted by the phrenic nerve.

Function

The fibrous sac provides slippery surfaces for the heart to beat inside and the lungs to move outside. Apart from the passage of the great vessels, all *inner surfaces* are slippery; the oblique sinus permits pulsation of the left atrium (a kind of 'cardiac bursa' like the omental bursa—lesser sac—behind the stomach). Apart from the bare area in front (from the midline halfway to the apex beat) and a bare strip posteriorly for the oesophagus, the whole of the *outer surface* of the fibrous sac is clothed with densely adherent parietal pleura, on which the breathing lungs glide.

Pericardial drainage

The needle is inserted in the angle between the xiphoid process and the left seventh costal cartilage at the costal margin, and directed upwards, backwards and slightly medially through the central tendon of the diaphragm into the pericardial cavity. The pleura and lung should be too far lateral to be damaged. For more prolonged drainage through an indwelling tube, the left fifth costal

cartilage is resected and the cavity opened through the bed of the cartilage after dividing the internal thoracic vessels.

HEART

The **heart** is the muscular pump responsible for blood circulation. It is an organ with four chambers—right and left atria, right and left ventricles—and, as seen from the front, is described as having right, inferior and left borders, an anterior or sternocostal surface, an inferior or diaphragmatic surface, a base or posterior surface, and an apex.

Position

Hold a heart in the position it occupies in the body and look at it from the front (Fig. 4.19). The **right border** consists entirely of the right atrium. The **inferior border** is made up mostly of right ventricle with a small portion of left ventricle, which itself forms the **apex**, at the junction of the inferior and left borders. The **left border** is mostly left ventricle, with the auricle of the left atrium forming the uppermost part of this border. The anterior or **sternocostal surface** consists of the right atrium, the vertical atrioventricular groove, and

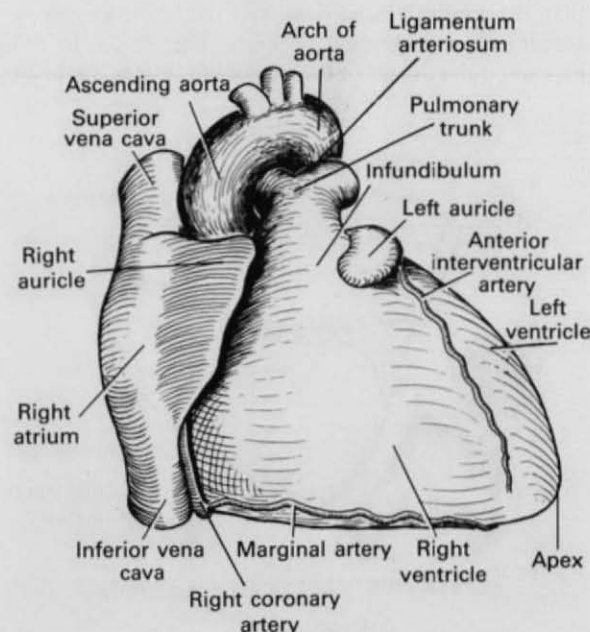


Fig. 4.19 Anterior (sternocostal) surface of the heart. The left auricle is shown somewhat enlarged as in most anatomical diagrams, but the normal auricle (as seen radiologically in this view) should present a slightly concave outline here.

the right ventricle, with a narrow strip of the left ventricle appearing on the horizon of the left border. The tip of the left auricular appendage peeps over this border. Now look at the heart from behind and below. The inferior, or **diaphragmatic surface** (Fig. 4.20) consists of the right atrium receiving the inferior vena cava, the anteroposterior atrioventricular groove and to the left of this the ventricular surface is made up of one-third right ventricle and two-thirds left ventricle, separated by the posterior interventricular branch of the right coronary artery. The left atrium is attached behind the right atrium, but at a higher level; it does not extend down to the diaphragmatic surface. The **posterior surface** (or base) of the heart (Fig. 4.21) consists almost entirely of the left atrium, receiving the four pulmonary veins. From it the left ventricle converges to the left towards the apex. To the right a narrow strip of right atrium forms the horizon, while below a small part of the posterior wall of the right atrium receives the coronary sinus.

The position of the heart varies a little between systole and diastole. The roots of the great vessels fix it, but the ventricles are free to move within the pericardium. The ventricles are narrower and slightly rotated during systole.

During descent of the central tendon of the diaphragm in full inspiration the apex of the heart descends more than the relatively fixed base, and the heart occupies a somewhat more vertical position (Fig. 4.10). In full expiration the ascent of the diaphragm forces the heart

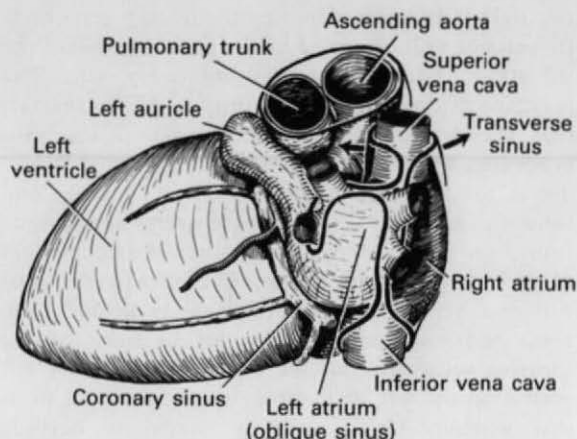


Fig. 4.21 Posterior view of the heart. The cut edges of the serous pericardium are shown by the heavy lines (compare with Fig. 4.18D).

into the more horizontal position characteristic of the cadaver (Fig. 4.9), but these differences in position are not very great.

Note that the *base* of the heart is the *posterior surface* (left atrium), and not the area from which the great vessels emerge at the top of the heart and which has no special name.

Surface markings

The *right border* of the heart extends from the lower border of the right third costal cartilage to the lower border of the right sixth costal cartilage, just beyond the right margin of the sternum and describing a slight convex curve between these points. The *inferior border* passes from the right sixth costal cartilage to the *apex*, which is normally in the left fifth intercostal space about 9 cm ($3\frac{1}{2}$ in) from the midline. From the apex the *left border* extends upwards to the lower border of the left second costal cartilage about 2 cm ($\frac{3}{4}$ in) from the sternal margin. These are the borders as seen in a typical radiograph of the normal heart, although the area of cardiac dullness as determined by percussion will be smaller. The apex beat is slightly medial to the surface projection of the apex.

Cardiopulmonary resuscitation

The airway and breathing aspects of CPR have been mentioned on page 254. For restoring **circulation**, a blow to the lower part of the sternum (*precordial thump*) with the side of a clenched fist may restore normal

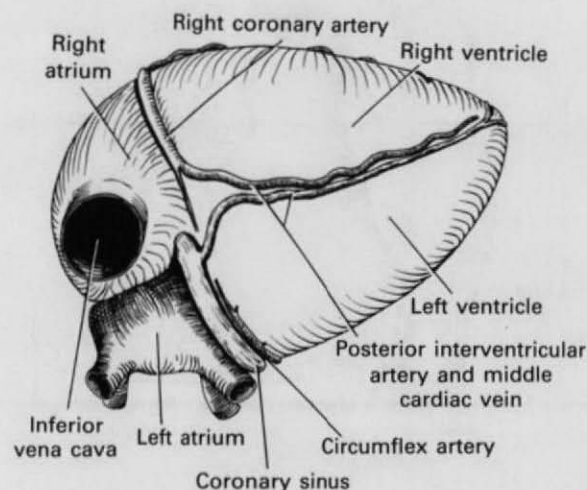


Fig. 4.20 Inferior (diaphragmatic) surface of the heart. The posterior interventricular artery and middle cardiac vein lie in the interventricular groove, with the coronary sinus in the atrioventricular groove.

beating in circulatory arrest, but usually external cardiac massage is required. With the operator at the side of the supine patient, the heel of one hand is placed over the lower end of the sternum above the xiphisternum, and the heel of the other hand placed over the first. With the elbows straight, the sternum is rhythmically compressed backwards for 4–5 cm about 60 times a minute, so squeezing the ventricles between the sternum and the vertebral column and stimulating the return of blood circulation.

For *external defibrillation*, one electrode is placed to the right of the sternum, and the other over the apex and towards the left midaxillary line.

Fibrous skeleton

The two atria and the two ventricles are attached to a pair of conjoined fibrous rings which, in the form of a figure 8, bound the atrioventricular orifices. The 'figure 8' lies on its side, very nearly in the sagittal plane. (A small bone, the *os cordis*, lies at the junction of the two rings in some animals). To this fibrous skeleton the muscle of the heart is attached; the muscle fibres encircle the chambers of the heart in a series of whorls and spirals. The atria lie to the right and the ventricles to the left of the fibrous skeleton and there is no muscular continuity between the two. The atrioventricular conducting bundle is the only physiological connection between atria and ventricles across the fibrous ring. The membranous part of the interventricular septum is attached to the fibrous skeleton, and so are the bases of the cusps of the tricuspid and mitral valves (Fig. 4.23).

Chambers

Clinically the heart is described as consisting of right and left sides. The right side propels blood to the lungs and the left side propels blood around the systemic circulation; separate failure of either side produces a chain of symptoms peculiar to itself. Anatomically, however, it should be noted that the 'right side' lies much more *in front of* than to the right of the 'left side', for the interatrial and interventricular septa lie almost in the coronal plane (Fig. 4.22).

The four chambers of the heart, the two atria and the two ventricles, possess anatomical features that will now be considered, in the order in which the circulating blood flows through them.

Right atrium

This elongated chamber lies between the superior and

inferior venae cavae, and forms the right border of the heart (Fig. 4.19). Its lower end is almost completely occupied by the orifice for the inferior vena cava but its upper end is prolonged to the left of the superior vena cava as the **right auricle**. This overlies the commencement of the aorta and the upper part of the right atrioventricular groove and, with the left auricle, it clasps the infundibulum (upper end) of the right ventricle. The left atrium lies behind the right atrium. From the angle between the superior vena cava and the right auricle a shallow groove sometimes descends; this is the *sulcus terminalis*. It is produced, when present, by the projection into the cavity of the right atrium of a vertical ridge of heart muscle, the *crista terminalis*. The interior of the right atrium is smooth to the right of the crista terminalis, but between the crista and the blind extremity of the auricle the myocardium is projected into a series of horizontal ridges like the teeth of a comb: the *pectinate muscles* (Fig. 4.22). This rough area represents the true auricular chamber of the embryonic heart. The remainder of the atrial cavity, smooth walled, is produced by incorporation of the right horn of the sinus venosus (p. 275).

The opening of the inferior vena cava is guarded by a ridge, the remains of the valve of the inferior vena cava, that is continued upwards towards the *opening of the*

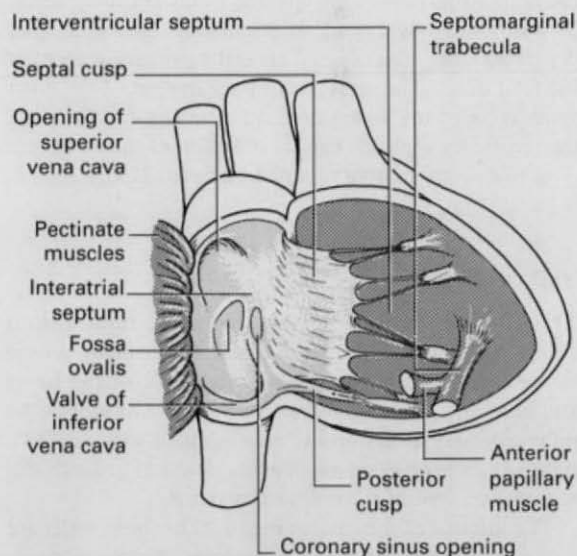


Fig. 4.22 Interior of the heart from the front. The anterior wall of the right ventricle, together with the anterior papillary muscle and anterior cusp of the tricuspid valve, have been removed. The anterior wall of the right atrium has been incised and the flap hinged towards the right to show the pectinate muscles. Note that the interventricular and interatrial septa lie across the body (in the coronal plane).

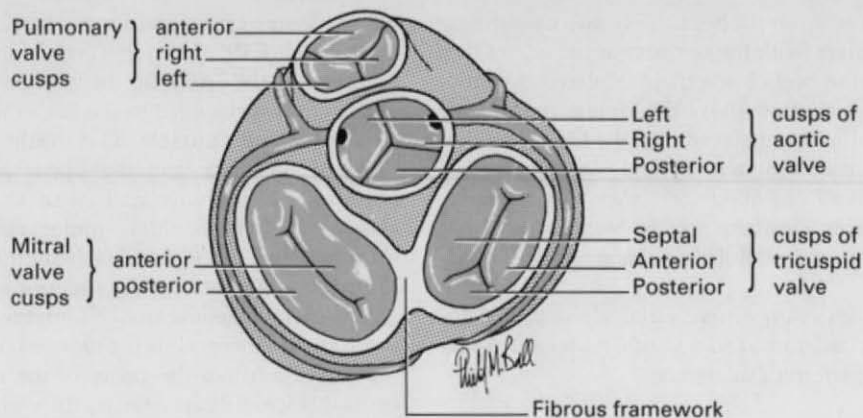


Fig. 4.23 Heart valves, from the right and above, after removal of both atria, the aorta and pulmonary trunk. Note the figure-of-eight fibrous framework round the mitral and tricuspid orifices. The pulmonary and aortic valve cusps are officially named from their fetal positions. Since there is some later rotation, many consider these names inappropriate and use alternatives, especially for the aortic cusps above which the coronary arteries arise: anterior instead of right, and left posterior instead of left.

coronary sinus. This opening lies above the septal cusp of the tricuspid valve, and to the left of the inferior vena caval orifice. It is big enough to admit the tip of the little finger of the owner of the heart (big man, big heart, big little finger).

The **interatrial septum** forms the posterior wall of the right atrium above the opening of the coronary sinus. Towards its lower part is a shallow saucer-shaped depression, the *fossa ovalis*. This is the primary septum of the fetal heart. The crescentic upper margin of the fossa ovalis is called the *limbus*, and indicates the lower edge of the secondary septum. Failure of fusion of the two septa gives rise to a persistent foramen ovale (p. 275).

Right ventricle

This chamber projects to the left of the right atrium (Figs 4.19 and 4.22). The *atrioventricular groove* between the two is vertical over the front of the heart and anteroposterior on the inferior surface. It lodges the right coronary artery and is usually filled with fat. The right ventricle narrows as it passes upwards towards the commencement of the pulmonary trunk.

The interior of the cavity (Fig. 4.22), whose walls are much thicker than those of the atrium, is thrown into a series of muscular ridges and bundles, the *trabeculae carneae*. One of these ridges has broken free and lies in the cavity attached by its two ends to the interventricular septum and the anterior papillary muscle. This is the *septomarginal trabecula* (formerly the moderator band (Fig. 4.22)); it contains part of the right branch of

the conducting bundle. Other bundles or bridges of muscle break free from the ventricular wall to form the *papillary muscles* which are attached to the cusps of the tricuspid valve.

The **tricuspid valve** guards the right atrioventricular orifice. It has three cusps and admits the tips of three fingers (the mitral valve has two cusps and admits two fingers). The three *cusps*, called *anterior*, *posterior* and *septal*, are attached by their bases to the fibrous atrioventricular ring and are arranged to lie against the three walls of the ventricle—*anterior*, *inferior* and *septal*. Note that the *posterior* cusp lies against the *inferior* wall or floor of the ventricle (Fig. 4.22); it is called posterior because it is behind the anterior cusp, but would be better called the inferior cusp. The cusps (leaflets) of both the tricuspid and mitral valves are more variable in size and shape than most textbooks suggest, and often appear to be subdivided but without forming complete additional leaflets. The edges and ventricular surfaces of the cusps receive the attachments of the *chordae tendineae*, inelastic cords which diverge from the papillary muscles and prevent the cusps from being everted when the ventricle contracts. Usually the large anterior papillary muscle is connected by chordae to the anterior and posterior cusps, a smaller posterior papillary muscle is attached to the posterior and septal cusps, and several small papillary muscles join the septal and anterior cusps.

The cavity of the right ventricle is flattened by the forward bulge of the interventricular septum. Thus the anterior wall and septum are of equal area, while the inferior wall (floor) is much narrower. The pos-

terior cusp of the tricuspid valve is correspondingly smaller than the other two (Fig. 4.23).

The cavity of the ventricle continues upwards into a narrowing funnel-shaped approach to the pulmonary orifice. The walls of this part, the *conus* or *infundibulum*, are thin and smooth, lacking trabeculae carneae. Here fibrous and elastic tissue progressively replace the heart muscle.

A fibrous ring at the top of the infundibulum gives attachment to the cusps of the **pulmonary valve**, at the commencement of the pulmonary trunk (p. 271). It is guarded by three semilunar *cusps* named *anterior*, *left* and *right* (see the caption for Fig. 4.23 and p. 276). The pulmonary orifice lies almost in the horizontal plane and is at a higher level than the aortic orifice.

Left atrium

The left atrium forms the posterior surface (base) of the heart, and lies behind the right atrium (Fig. 4.21), the interatrial septum forming the common boundary wall. The inferior margin of the left atrium lies a little above that of the right atrium, whose posterior wall here receives the coronary sinus. From the left atrium the left ventricle slopes away to the apex. It has a small auricle that projects from its upper border and passes to the left over the atrioventricular groove and peeps around the convexity of the left side of the infundibulum (Fig. 4.19). The four pulmonary veins enter it symmetrically, one above the other on each side. They are enclosed, with the superior and inferior venae cavae, in a common sleeve of serous pericardium (Fig. 4.21). The posterior surface of the left atrium between the pulmonary veins forms the anterior wall of the oblique sinus of the pericardium. The fibrous pericardium separates this surface from the oesophagus.

The cavity of the left atrium is smooth-walled except in the auricle; here muscular ridges indicate that the appendage was the original auricular chamber of the embryonic heart. All the smooth-walled portion is derived by incorporation of the embryonic pulmonary veins into the atrial cavity. In the embryo two veins from each lung unite to form the right and left pulmonary veins which open by a common pulmonary vein into the left auricle (p. 276). The common pulmonary vein and the right and left pulmonary veins dilate and are incorporated into the wall of the atrium, which thus receives four separate veins. Should this process be arrested during embryonic development, the atrium may receive three, two, or only one pulmonary vein. Three veins in place of the usual four are fairly commonly found, but two or only one are almost unknown except in abortions, because they are accom-

panied by other defects of cardiac development incompatible with life.

The bicuspid **mitral valve** admits the tips of two fingers (the tricuspid valve, with three cusps, admits the tips of three fingers). The *cusps* are named *anterior* and *posterior* (Fig. 4.23). The anterior cusp lies *between the mitral and the aortic orifices*. The bases of the cusps are attached to the margins of the fibrous atrioventricular ring. Usually the attachments of the two cusps are continuous around the orifice, but sometimes they fail to meet and a small accessory cusp fills the gap between them. The mitral cusps are smaller in area and thicker than those of the tricuspid valve and consequently are not ballooned back so much into the atrium during ventricular systole. The anterior cusp of the mitral valve is thicker and more rigid than the posterior cusp.

Left ventricle

The walls of this cavity are three times as thick as those of the right ventricle (Fig. 4.24). The *interventricular septum* (see below) bulges into the cavity of the right ventricle, so that in cross section the left ventricle is circular, the right crescentic. *Trabeculae carneae* are well developed. There are two *papillary muscles*, *anterior* and *posterior*, the anterior being the larger. Both are connected by *chordae tendineae* to each valve cusp (Fig. 4.25). The posterior cusp receives the chordae on both its margin and its ventricular surface, but since blood is squirted across both surfaces of the anterior cusp (down through the mitral orifice and up to the aortic) the chordae are attached to it only along its margins. The upper and right end of the septal wall is smooth; between the smooth part and the anterior cusp of the mitral valve is the *aortic vestibule*, which leads up to the aortic orifice.

Open a heart and place the left index finger in the aortic vestibule, its tip passing through the aortic valve. Anterior to the finger is the interventricular septum tapering down abruptly to the membranous part. Posterior is the anterior cusp of the mitral valve. Now pass the right index finger from the left atrium into the left ventricle. The two index fingers lie touching, pointing in opposite directions; only the anterior cusp of the mitral valve separates them. This is the pathway of the blood stream.

The **interventricular septum** lies vertically from side to side across the body: the cavity of the right ventricle lies in front of it and that of the left ventricle behind it. It is marked on the surface of the heart by the interventricular branches of right and left coronary arteries. Its muscle wall, equal in thickness to that of the left ventricle, bulges forward into the cavity of the right ventricle. At its attachment to the fibrous skeleton

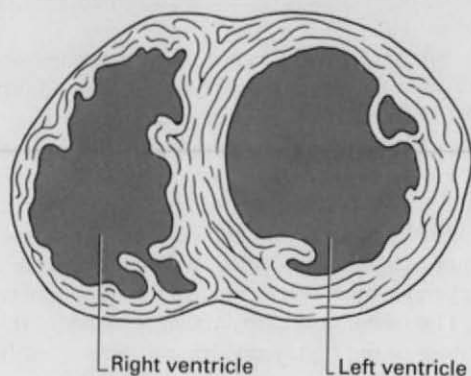


Fig. 4.24 Transverse sections of the ventricles, from below. The wall of the right ventricle is three times as thick as that of the left.

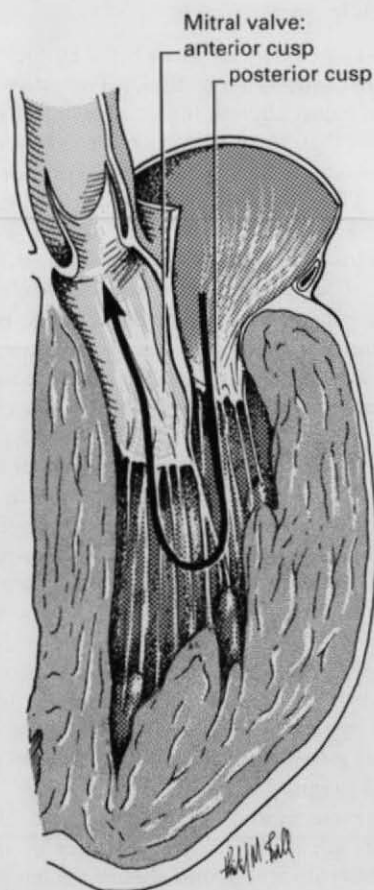


Fig. 4.25 Interior of the left ventricle, in a sagittal section viewed from the left, to show the cusps of the mitral valve. The arrow indicates the path of blood, entering from the left atrium behind the anterior cusp and leaving the ventricle in front of the anterior cusp to pass through the aortic valve.

(conjoined atrioventricular rings) it is thinner and more fibrous. This is the *membranous* part of the septum, and the aortic vestibule lies between it and the anterior cusp of the mitral valve (Figs 4.23 and 4.25).

The aortic orifice is guarded by the **aortic valve**, at the entrance to the ascending aorta. It lies at a lower level than the pulmonary orifice, rather to its right side (Fig. 4.23), and is more obliquely placed. Its three semilunar *cusps* are named *right*, *left* and *posterior* (in contrast to the anterior, right and left cusps of the pulmonary valve; see the caption for Figure 4.23 and p. 276).

Structure of heart valves

The cusps of the tricuspid and mitral valves are all similar. They are flat and their free edges are serrated in outline by the attachment of the chordae tendineae. On closure of the valves during ventricular systole the cusps do not merely meet edge to edge, but come into mutual contact along strips of their auricular surfaces near the serrated margins. This contact and the pull of the marginal chordae prevent eversion of the free edges into the cavity of the atrium, and the centrally attached chordae limit the amount of ballooning of the cusps towards the atrium. The tricuspid and mitral valves are kept competent by active contraction of the papillary muscles, which pull on the chordae during ventricular systole. The chordae tendineae also act, as it were, in reverse, helping to prevent ventricular stretching.

The cusps of the pulmonary and aortic valves are similar to each other. The free edge of each cusp contains a central fibrous nodule from each side of which straight edges slope at 120° from each other to the attached base of the cusp. Three cusps lying edge to edge thus close the circular orifice. The cusps are cup-shaped, and from their free and attached (scalloped) margins they bulge down in a globular convexity towards the cavity of the ventricle. During ventricular systole the bulge of the sinuses above the cusps prevents the cusps from becoming flattened against the walls of the sinuses; the residual blood in the sinuses forms vortices which help the elastic recoil of the cusps at the end of systole. During ventricular diastole pressure of blood above the valves distends the cusps, so that their free edges are forced together. Competence of the pulmonary and aortic valves is thus a passive phenomenon, the result of mutual pressure between the distended cusps, and depending on the integrity of their straight edges.

Microscopically the valves of the heart are composed of fibrous tissue in which many elastic fibres are found. They are covered on each surface by vascular endothelium.

Surface markings of valves

The surface markings of the heart itself have been considered on page 266. As far as the valves are concerned, they all lie behind the sternum, making a line with each other that is nearly vertical (Fig. 4.26). The bases of tricuspid and mitral valves, attached to the atrioventricular ring, are indicated by vertical lines over the lower part of the sternum. The tricuspid valve lies behind the midline of the lower sternum, the mitral valve, overlapping it, lies higher and somewhat to the left. The aortic and pulmonary orifices lie behind the left border of the sternum at the third costal cartilage; the pulmonary is the higher of the two.

Knowledge of the surface markings of the heart valves has little application in auscultation of the heart. The normal heart sounds are produced by closure of heart valves, and the opening snap of the mitral valve may also be audible, but these sounds are by no means heard best directly over the valves concerned. They are heard best (Fig. 4.26) where the blood-containing chambers lie nearest to the chest wall. For the tricuspid valve this is over its surface, but for the mitral valve it is at the apex beat, where the cavity of the left ventricle lies nearest the surface. For the aortic valve it is where the ascending aorta lies nearest the surface, at the right sternal margin in the second intercostal space. For the pulmonary valve it is at the left sternal margin at the third costal cartilage (over the infundibulum of the right ventricle).

Great vessels

In their course through the pericardial cavity the great vessels are invested with a reflexion of serous pericardium between the parietal and visceral layers. The ascending aorta and pulmonary trunk share a common sleeve of serous pericardium in which they lie completely free in front of the transverse sinus (Fig. 4.21). The pulmonary trunk inside the fibrous pericardium measures 4 cm ($1\frac{1}{2}$ in) while the ascending aorta is slightly longer.

The six veins share another common sleeve of serous pericardium (Fig. 4.21). The four pulmonary veins (described on p. 269) and the inferior vena cava (p. 263) are all 1 cm ($\frac{1}{2}$ in) or less in length within the pericardium, but the superior vena cava (p. 259) courses for about three times that distance through the pericardial cavity before entering the right atrium.

Ascending aorta

Immediately above the aortic orifice the wall of the **ascending aorta** bulges to make the *aortic sinuses*, one

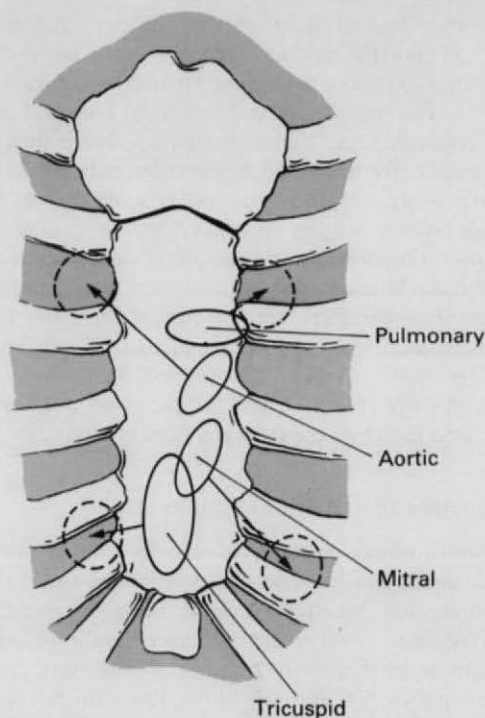


Fig. 4.26 Surface markings of the heart valves. The arrows indicate the directions in which the sounds of the closing valves are propagated, and the circles indicate the generally preferred sites for auscultation.

above each cusp and similarly named. From the right sinus the right coronary artery emerges; from the left sinus, the left coronary artery. Above the sinuses the aorta runs to the right of the pulmonary trunk and as it passes upwards it slants a little forward towards the manubrium before curving backwards at the commencement of the arch. Here the fibrous pericardium is blended with its wall. The ascending aorta, over 5 cm (2 in) long, makes a gentle spiral with the pulmonary trunk on its left side (Fig. 4.19), both within the common sleeve of serous pericardium. The branches of the ascending aorta are the coronary arteries, described on page 273.

Pulmonary trunk

Commencing at the pulmonary orifice, which is at a slightly higher level than the aortic orifice (Fig. 4.26), the wide **pulmonary trunk** arches backwards to the left of the ascending aorta, the two vessels making the gentle spiral enclosed in the common sleeve of serous pericardium in front of the transverse sinus (Fig. 4.21). The trunk passes backwards and emerges from the fibrous pericardium to divide in the concavity of the

aortic arch and in front of the left main bronchus (Fig. 4.31) into the *right* and *left pulmonary arteries*, which enter the lung roots with their corresponding bronchi (p. 283). The trunk is about 5 cm (2 in) long and most of it lies within the pericardial cavity. Note that the proper name for this vessel is the *pulmonary trunk*, not the *pulmonary artery*; the pulmonary trunk divides into the *right pulmonary artery* and the *left pulmonary artery*.

Catheterization. Various aspects of cardiorespiratory function can be monitored by pulmonary artery catheterization. The catheters are introduced into the right atrium, usually via the internal jugular or subclavian veins (p. 439 and 442) and carried on through the tricuspid valve into the right ventricle and pulmonary trunk, and then into the right pulmonary artery.

Conducting (conduction) system

The **conducting system** is usually considered to consist anatomically of two main components: (1) the *sinuatrial node* (SA node), and (2) the *atrioventricular node* (AV node), the *atrioventricular bundle* (of His), the right and left limbs or branches of the bundle, and the subendocardial Purkinje fibres. From the SA node, which, like the AV node and its extensions, is composed of a specialized type of cardiac muscle fibres (not nervous tissue), impulses are conducted to the AV node by atrial cardiac muscle fibres. Many authorities consider that a third component of the system, the *internodal tracts*, forms preferential pathways for conduction between the nodes, with a rate of impulse transmission twice as fast as through ordinary atrial muscle. While these tracts can be demonstrated physiologically, there has been no agreement that they can be defined anatomically. The AV node, bundle, branches and subendocardial fibres form one continuous mass of conducting tissue; the node is really just the name given to the proximal end of the bundle.

Sinuatrial node

This mass of tissue, the pacemaker of the heart, is usually crescent-shaped and situated within the muscle fibres of the right atrium just below the superior vena cava near the top of the crista terminalis (Fig. 4.27), and passing back and to the left into the wall of the right auricle for 1–2 cm. It is about 5 mm thick at its widest part. Rarely it becomes more horseshoe-shaped, continuing into the posterior part of the auricle and atrium. The node contains the central stellate cells—pacemaker or P cells—which generate the impulses for contraction; they contain fewer myofilaments than ordinary cardiac muscle cells.

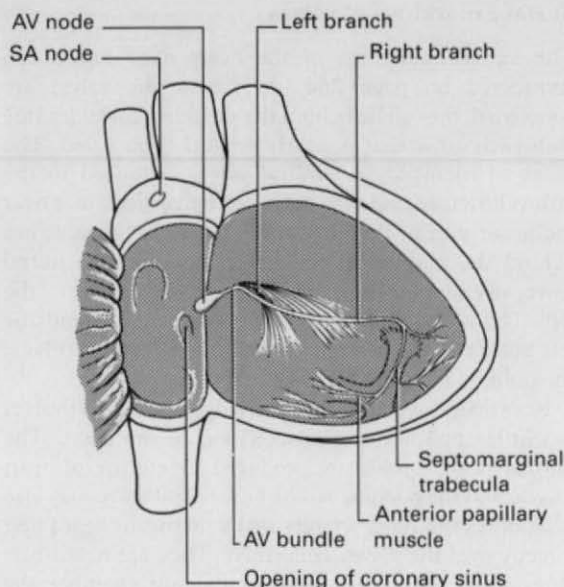


Fig. 4.27 Conducting system of the heart, from the front after removal of parts of the right atrium and the ventricles. This diagrammatic representation illustrates that the left and right branches of the AV bundle, which pass down their respective sides of the interventricular septum, are very different. The left branch rapidly breaks up into a sheaf of subendocardial fibres, but the right continues towards the septomarginal trabecula; part of the branch enters it to reach the anterior papillary muscle. Only the more proximal parts of the subendocardial fibres are shown.

Atrioventricular node, bundle and branches

The **AV node** is buried in the muscle of the interatrial septum, above and to the left of the opening of the coronary sinus. More precisely it lies deep to *Koch's triangle* (the surgical landmark for the node), a small area bounded by the base of the septal cusp of the tricuspid valve, the anteromedial margin of the opening of the coronary sinus, and a palpable collagenous band (the tendon of Todaro) 1 mm in diameter running from the right fibrous trigone to the medial edge of the valve of the inferior vena cava. From the node, the **AV bundle** runs upwards in the right fibrous trigone beneath the attachment of the septal cusp and then along the inferior border of the membranous part of the interventricular septum, where it divides into right and left branches. Because the fibrous framework of the heart separates the muscles of the atria from those of the ventricles, the bundle is the only means of conducting the contractile impulse from atria to ventricles. The *right branch* runs at first within the muscle of the septum and then becomes subendocardial on the right side of the septum. Much of it continues into the septomar-

ginal trabecula (moderator band) to reach the anterior papillary muscle and the anterior wall of the ventricle, and its Purkinje fibres then spread out beneath the endocardium. The *left branch* reaches the septal endocardium of the left ventricle and rapidly breaks up into a sheaf of branches which spread out subendocardially over the septum and the rest of the ventricular wall.

Blood supply of the heart

The heart is supplied by the two **coronary arteries** and their branches (Fig. 4.28). The companion veins do not have names that correspond to those of the arteries; in this respect the heart resembles the brain.

The right and left coronary arteries arise from aortic sinuses at the beginning of the ascending aorta and run in the respective atrioventricular grooves. There are two principal branches from each; marginal and posterior interventricular from the right coronary, and circumflex and anterior interventricular from the left coronary, together with other named branches.

Right coronary artery. Arising from the right aortic sinus the artery passes between the right auricle and the infundibulum of the right ventricle (Fig. 4.28). Passing now *vertically downwards* in the atrioventricular groove the artery turns backwards at the inferior border of the heart and runs posteriorly. It gives off branches to both atrium and ventricle as it passes vertically downwards. One of the highest branches is the *conus artery* which passes upwards and medially on the front of the conus part (infundibulum) of the right ventricle. The largest atrial branch, arising from the first centimetre or two of the main vessel, is usually the *SA nodal artery* which forms a vascular ring in the right atrium and auricle below the superior vena caval opening. It supplies the SA node in about 60% of hearts (below), and may arise directly from the anterior aortic sinus adjacent to the right coronary itself, in which case this sinus has two openings. At the inferior border the *right marginal artery* passes to the left along the right ventricle, although it often has a much higher origin and passes obliquely down over the front of the ventricle. Posteriorly at the top of a characteristic upward 'kink' is the origin of the *AV nodal artery*. On the diaphragmatic surface of the heart the *posterior interventricular* branch is given off. This large vessel passes along the interventricular groove towards the apex of the heart. Its name of 'posterior' interventricular artery is a misnomer; 'inferior' would seem more appropriate, though it is often called by clinicians the posterior descending artery. The part of the right coronary artery now remaining is much smaller than its interventricular branch. It passes backwards to anastomose by terminal arterioles with the termination of

the circumflex branch of the left coronary artery at the lower part of the left atrium (Fig. 4.20).

Left coronary artery. Arising from the left aortic sinus *behind the pulmonary trunk* (from which it may have an anomalous origin) the vessel emerges between the left auricle and the infundibulum of the right ventricle. After this short course it divides into its two main branches. The *circumflex branch*, which is really the continuation of the parent trunk but with a change of name, continues down to the back of the heart in the atrioventricular groove, giving off various ventricular branches and anastomosing with the end of the right coronary. In the first few millimetres of its course in 40% of hearts it gives off the *SA nodal artery* which passes to the right behind the ascending aorta and above the upper left pulmonary vein to reach the right atrium and auricle. The *anterior interventricular artery*, which is the cardiac vessel most often affected by disease and frequently called by clinicians the left anterior descending artery, runs down in the interventricular groove to anastomose under the apex with the posterior interventricular branch of the right coronary.

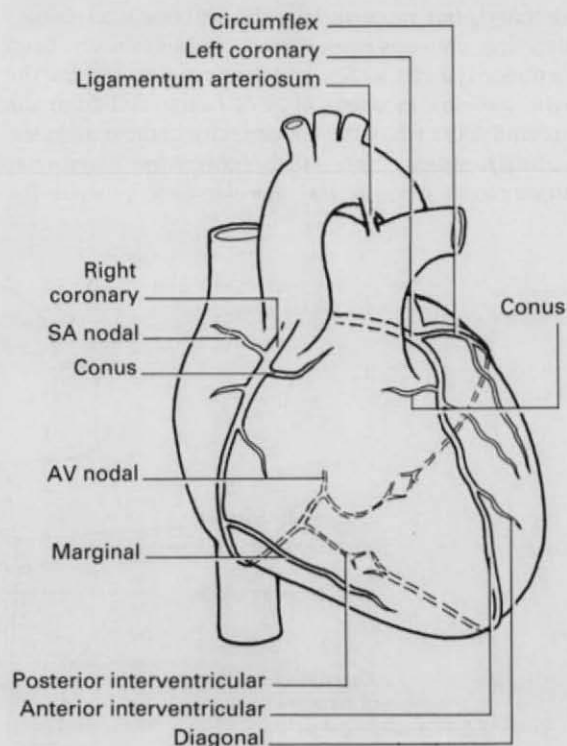


Fig. 4.28 Coronary arteries and their main branches, seen from the front. The vessels not on the anterior surface are shown in interrupted line.

It usually gives off towards the left several large *ventricular branches* (called by radiologists *diagonal* and *obtuse marginal vessels*), but near its origin there is a *conus branch* that runs on to the upper part of the right ventricle, providing a potential anastomosis with the conus branch of the right coronary.

The above 'standard' description must be modified by stating that there is considerable variation in the way the major branches end and anastomose (particularly the interventricular vessels) and in the areas supplied by each vessel. In about 10% of hearts the right coronary is shorter than usual and the posterior interventricular artery is given off by a large anterior interventricular from the left coronary; in this case the heart is said to show 'left dominance'. In the more common 'right dominance' the posterior interventricular comes from the right coronary; the artery giving off the posterior interventricular branch is defined as the dominant artery. Most of the interventricular septum is usually supplied by penetrating septal branches from the anterior interventricular, with only a small posterior part by the posterior interventricular. The AV node and bundle and the first few millimetres of the branches receive their supply from the AV nodal artery (right coronary), but more distally the anterior interventricular (left coronary) takes over. It has already been mentioned that the SA nodal artery arises from the right coronary in about 60% of hearts and from the circumflex branch of the left coronary in the remainder.

Anastomoses of the coronary arteries. Anastomoses exist at the arteriolar level between the

terminations of the right and left coronary arteries in the atrioventricular groove and between their interventricular and conus branches. These anastomoses on the surface of the heart are insignificant. In the interventricular septum and in the posterior wall of the left ventricle there are *very free anastomoses* between the interventricular arteries, but still *by arterioles only*. The time factor in occlusion is all important; in slow occlusion there is time for healthy arterioles to open up, in abrupt occlusion there is not.

Potential anastomoses exist between the coronary arteries and pericardial arteries around the roots of the great vessels. These pericardial arteries are derived from the pericardiophrenic, the bronchial and the internal thoracic arteries. In *very rare* instances one of these may open up to replace a coronary artery.

Veins of the heart. The veins of the heart (Fig. 4.29) fall into three groups: the *venae cordis minimae*, the anterior cardiac veins, and the coronary sinus with its five normal tributaries—the great, middle and small cardiac veins, the posterior vein of the left ventricle and the oblique vein of the left atrium. The coronary sinus receives almost all of the heart's blood.

The **coronary sinus** lies in the posterior part of the atrioventricular groove (Fig. 4.21), covered by a thin layer of myocardium, and opens at its right (lower) end into the posterior wall of the right atrium to the left of the inferior vena caval opening. Embryologically it may be said to commence at a valve alongside the entrance of the oblique vein (of Marshall) of the left atrium (p. 275). It is a wide-bored vessel about 3 cm ($1\frac{1}{2}$ in) long, with the

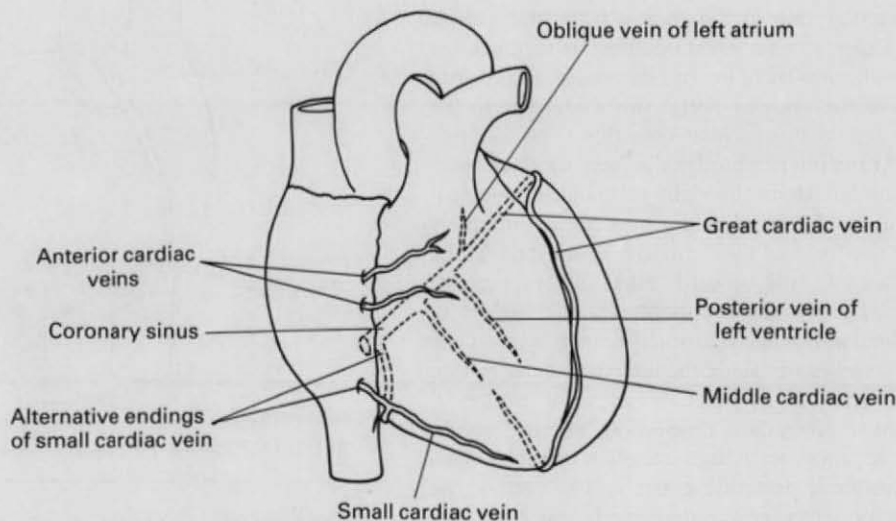


Fig. 4.29 Cardiac veins, seen from the front. The vessels not on the anterior surface are shown in interrupted line.

so-called valve of the coronary sinus (below) at its opening. The **great cardiac vein** (Fig. 4.29) accompanies the anterior interventricular and circumflex arteries to enter the upper (left) end of the sinus, receiving in its course a number of left ventricular tributaries. The **middle cardiac vein** accompanies the posterior interventricular artery and opens near the termination of the coronary sinus. The **small cardiac vein** accompanies the marginal branch of the right coronary artery (if that vessel really is at the lower margin of the heart) and is usually said to open into the lower end of the coronary sinus. However, it frequently drains directly into the right atrium through its anterior wall, in which case the vein can be said merely to be the lowest anterior cardiac vein. The **posterior vein of the left ventricle** joins the sinus to the left of the middle cardiac vein, and the small **oblique vein of the left atrium** runs downwards into the left end of the sinus.

The **anterior cardiac veins** are a series of parallel veins that run across the surface of the right ventricle to open into the right atrium (Fig. 4.29). They drain independently into the right atrium by dipping into the anterior atrioventricular groove. In this vertical groove it is common to find a vein (lying at right angles to the anterior cardiac veins) which receives two or more of the veins and itself opens into the right atrium.

The **venae cordis minimae** are small veins in the walls of all four chambers of the heart that open directly into the respective chambers. They appear to be most frequent in the right atrium; their numbers have been exaggerated in the past, and their contribution to venous return is negligible.

Lymph drainage

The lymphatics of the heart drain back along the coronary arteries, emerge from the fibrous pericardium along with the aorta and pulmonary trunk, and empty into the tracheobronchial lymph nodes and mediastinal lymph trunks.

Nerve supply

The heart is innervated by the cardiac plexus, which has been described on page 259 together with the pathways for cardiac pain. There are baroreceptors in the wall of the aortic arch (p. 256) and in the carotid sinus (p. 438) for the reflex control of heart rate.

Development

The earliest stages of cardiac development have been mentioned on page 44. Now that the adult heart has

been described, some further details of development can be added.

The original single atrium becomes partitioned by the formation of two septa. The **primary septum** (septum primum) grows down towards the endocardial cushions at the atrioventricular orifice but does not immediately fuse with them; the gap remaining above the cushions is the **primary foramen** (foramen primum). Before this foramen becomes obliterated by further downgrowth of the septum, a new foramen (**secondary foramen**, foramen secundum) appears in the upper part of the primary septum. The right and left parts of the atrium thus still remain in communication. Now a further septum appears (**secondary septum**, septum secundum), on the right of the primary septum. It does not grow down as far as the cushions but ends at a curved postero-inferior border. The gap under the secondary septum which leads through to the secondary foramen in the primary septum is the **foramen ovale**, allowing fetal blood to flow from one side to the other. At birth when the lungs begin to function (p. 46), the pressure in the left atrium increases, forcing the two septa together so that they fuse, making a complete **interatrial septum**. The lower edge of the secondary septum remains as the **limbus** of the **fossa ovalis**; the floor of the fossa is the part of the primary septum not overlapped by the secondary septum. Note that the **secondary foramen** belongs to the **primary septum**, not the secondary septum.

The **sinus venosus** opens into the right atrium by a vertical opening (to the right of the secondary septum) guarded by flaps of tissue, the right and left **venous valves** (which in appearance resemble the lips of the ileocaecal valve). The upper ends of the valves fuse together forming a small ridge (the **septum spurium**). The rest of the left venous valve fuses with the interatrial septum. The septum spurium and the upper part of the right venous valve persist as the **crista terminalis**, and the lower part becomes the **valve of the inferior vena cava** and the **valve of the coronary sinus**. These two veins have come to open into the right atrium because the part of the sinus venosus into which they originally opened (the right horn) has become incorporated into the wall of the atrium, forming its smooth part; the rough part with the pectinate muscles (which includes the auricle) represents the original atrium. The rest of the sinus venosus persists as the **coronary sinus**, with the left horn being represented by the **oblique vein of the left atrium** (vein of Marshall).

The left atrium incorporates the ends of the pulmonary veins to such an extent that only the auricle represents the original atrium.

The channel between the original atrium and ventricle (atrioventricular canal) becomes constricted

by internal dorsal and ventral swellings, the *endocardial cushions*, and these meet to convert what was a single passage into the two atrioventricular orifices. Subendocardial tissue at these sites produces the mitral and tricuspid valves.

In the floor of the original ventricle, a partition grows upwards to become the *muscular part* of the *interventricular septum*. However, it does not grow as far as the endocardial cushions, but leaves a gap (*interventricular foramen*), which will become filled in by the *fibrous part* of the septum. It is important to appreciate that the muscular part of the septum does not grow up in the middle of the primitive ventricle but really at the junction of the ventricle and the bulb, so that the original ventricle becomes the left ventricle and the adjacent part of the bulb becomes the rough (trabecular) part of the right ventricle. The distal part of the bulb forms the smooth (outflow) part of the right ventricle, which continues upwards into the part of the bulb called the *truncus arteriosus*. This becomes divided into two by internal swellings, the right and left *bulbar ridges*, which meet to form the *aorticopulmonary septum*, so that the single tube becomes the ascending aorta and pulmonary trunk. The bulbar ridges are not vertical but assume a spiral form, possibly because of the pattern of blood flow, hence the way the aorta and pulmonary trunk curl round one another. It is the fusion of the lower ends of the bulbar ridges with the posterior endocardial cushion which creates the fibrous part of the interventricular septum.

The junction of the truncus arteriosus and the definitive ventricles is the site where the *aortic* and *pulmonary valves* develop. The lower end of the left bulbar ridge divides to form the left cusps of both the aortic and pulmonary valves; similarly the right cusps of both valves are formed from the right ridge. The third cusp of each valve is formed from a swelling in the dorsal (aortic) and ventral (pulmonary) walls respectively of the original tube, hence the names posterior for the third aortic cusp and anterior for the third pulmonary cusp. This is the fetal position from which the adult cusps are named, but later growth causes some rotation which leads some authorities to use alternative names (see the caption for Fig. 4.23).

The SA node develops from sinus venosus tissue but the AV node and bundle are derived from the original atrium.

Congenital defects. Among the commoner congenital defects of cardiac development are malformations of the interatrial and interventricular septa, and Fallot's tetralogy. Defects of the *interatrial septum* range from pinholes of no significance to large gaps due to failure of closure of the foramen ovale or associated maldevelopment of the primary or secondary septa. Inter-

ventricular septal defects are commonly in the fibrous part. *Fallot's tetralogy* is due to unequal division of the truncus arteriosus, giving a small pulmonary trunk and a large ascending aorta, and hence the tetrad of (1) pulmonary stenosis, (2) right ventricular hypertrophy, (3) a defect of the fibrous part of the interventricular septum, and (4) an over-riding aorta (sitting astride both ventricles because of the septal defect).

Other anomalies, such as patent ductus arteriosus and coarctation of the aorta, although commonly classified as 'cardiac' defects, are strictly speaking anomalies of the great vessels, and are considered on page 40.

Surgical approach

Many operations on the heart are carried out through a median sternotomy (p. 254), although some require a left thoracotomy. In the former, after splitting the sternum and dividing the thymus into its two lobes, the pericardium is incised in the lines of an inverted T, with the vertical incision extending as high as the pericardial reflexion from the aorta and the transverse incisions along the reflexions from the diaphragm. For *cardiopulmonary bypass* (to keep the circulation going during open heart surgery), the superior and inferior venae cavae are cannulated through the wall of the right atrium, in order to deliver blood to the oxygenating machine. The oxygenated blood is delivered to the aorta through a cannula in the aortic arch proximal to the brachiocephalic trunk. Some of this blood will pass downwards into the ascending aorta and so perfuse the coronary vessels whose openings are just above the aortic valves (kept closed by the pressure of the incoming blood).

In earlier *coronary artery bypass* operations, a suitable length of great saphenous vein was anastomosed at one end to the ascending aorta and at the other to the appropriate coronary vessel distal to the site of blockage. The vein, of course, must be turned upside down so that any valves in the chosen segment do not obstruct the arterial flow. Current opinion now often favours the use of the internal thoracic artery; the proximal end remains intact at its subclavian origin and the cut lower end is anastomosed to the coronary vessel.

For the repair of *atrial septal defects*, the right atrium is incised along its right border, avoiding the region of the SA node. For *ventricular septal defects* the front of the right ventricle can be incised vertically or transversely avoiding any obvious arteries or veins. For operations on the *mitral valve*, the left atrium is entered from the *right* through an incision behind the interatrial groove and in front of the two pulmonary veins.

Transplantation. The patient's heart is removed by

incisions through the aorta, pulmonary trunk and both atria. The incision line through the right atrium leaves the two venae cavae, the posterior wall of the atrium and the region of the SA node in situ. The posterior part of the left atrium with the four pulmonary vein orifices is also left intact. The donor heart is trimmed through the atria to match up with the remains of the patient's atria, although the lower end of the donor superior vena cava remains attached to the right atrium so that the donor heart retains its own SA node. For combined heart-lung transplantation, the donor block is removed through the trachea, right atrium and aorta, and sutured to the recipient in that order.

PART 7

POSTERIOR MEDIASTINUM

The posterior mediastinum is the space posterior to the pericardium and to the diaphragm. It is continuous directly, via the posterior part of the superior mediastinum, with the tissue spaces behind the pretracheal fascia and in front of the prevertebral fascia, that is, with the retropharyngeal space and the spaces lateral to trachea and oesophagus, between these tubes and the carotid sheaths. It is bounded posteriorly by thoracic vertebrae 4–12 and anteriorly above by the pericardium (left atrium) and below by the posterior sloping fibres of the diaphragm (Fig. 4.11). It contains some structures proper to itself and others that pass between the superior mediastinum and the abdomen. These latter structures will be described as a whole during their intrathoracic course.

DESCENDING (THORACIC) AORTA

This great arterial trunk commences at the lower border of T4 vertebra, where the arch of the aorta ends (Fig. 4.15). At first to the left of the midline, the vessel slants gradually to leave the posterior mediastinum in the midline at the level of T12 vertebra by passing behind the diaphragm between the crura (i.e. behind the median arcuate ligament). It gives off from each side nine posterior intercostal arteries (p. 248), a subcostal artery (p. 360), bronchial arteries (p. 285) and some small oesophageal vessels (see below).

OESOPHAGUS

This muscular tube extends from the cricoid cartilage (at the level of C6 vertebra) to the cardiac orifice of the stomach (at the level of T10 vertebra and the left seventh costal cartilage). It is 25 cm (10 in) long.

The cervical portion of the oesophagus (p. 434), lying in front of the prevertebral fascia, inclines slightly to the left of the midline, but enters the thoracic inlet in the midline in front of the body of T1 vertebra. Passing downwards now through the superior mediastinum (Fig. 4.14) the tube is slightly to the left of the midline behind the left bronchus, which may indent it slightly, as seen radiographically. The oesophagus, all this time in contact with the vertebral bodies, now inclines forward with a concavity more marked than that of the vertebral column, passes in front of the descending thoracic aorta (Fig. 4.15), in contact with the pericardium, and pierces the diaphragm 2.5 cm (1 in) to the left of the midline, opposite the body of T10 vertebra. This level can be indicated on the anterior body wall on the seventh left costal cartilage a thumb's breadth from the side of the sternum. Fibres from the *right* crus of the diaphragm sweep around the oesophageal opening in a sling-like loop (p. 249). The intra-abdominal part of the oesophagus varies in length according to the tone of its muscle and the degree of distension of the stomach. It averages 1–2 cm.

In the superior mediastinum the oesophagus is crossed by the arch of the aorta on its left side, and the vena azygos on its right (Figs 4.14 and 4.15). Just below the bifurcation of the trachea, in the posterior mediastinum, it is crossed anteriorly by the *left* main bronchus and the *right* pulmonary artery (Fig. 4.31). The thoracic duct lying at first behind it to the right, ascends with an inclination to the left, and in the superior mediastinum lies on the prevertebral fascia to the left of the oesophagus. The mediastinal pleura touches the oesophagus in places, particularly on the right side, where low down there is a pocket of pleura between the oesophagus and the aorta, but nowhere is the pleura attached to the oesophagus.

Above the oesophageal opening in the diaphragm, firm connective tissue connects the posterior surface of the oesophagus to the aorta; it is the loosening of this attachment which allows the oesophagus to rise in the sliding type of hiatus hernia (p. 251). At the level of the oesophageal opening, the anterior wall of the oesophagus is only very loosely attached to the margin of the opening, so allowing for diaphragmatic movement during respiration and the opening and closing of the cardia.

Constrictions. The narrowest part of the oesophagus is its commencement at the cricopharyngeal sphincter (p. 488), 15 cm (6 in) from the incisor teeth. Other sites where slight constrictions may be expected are where it is crossed by the aortic arch 22 cm (9 in) from the teeth, by the left principal bronchus (at 27 cm or 11 in), and where it passes through the opening in the diaphragm (38 cm or 15 in). Although the left

atrium is in front of the lower part below the left bronchus, it is only when enlarged that the atrium causes an indentation in the oesophagus.

Blood supply

The upper oesophagus, from the cricoid cartilage down to the level of the arch of the aorta in the superior mediastinum, is supplied by the inferior thyroid arteries, the middle portion by oesophageal branches from the aorta, and the lower part by the oesophageal branches of the left gastric artery. Venous return from the upper part is to the brachiocephalic veins, from the middle part to the azygos veins, and from the lower reaches by oesophageal tributaries of the left gastric vein, which empties into the portal vein. Thus there exists, in the lower part of the oesophagus, an anastomosis between portal and systemic venous systems. This anastomosis lies level with the central tendon (T8 vertebra) well above the oesophageal hiatus in the diaphragm. In cases of portal obstruction varicosities of these veins occur, and their rupture may give rise to serious or fatal haemorrhage.

Lymph drainage

Lymph channels from the oesophagus follow the arteries, and so lead to deep cervical nodes near the origin of the inferior thyroid artery, to the tracheo-bronchial group, and to the preaortic nodes of the coeliac group. However, within the oesophageal walls there are lymphatic channels which enable lymph to pass for long distances within the viscus so that drainage to one particular group of nodes from any given area cannot be relied upon.

Nerve supply

The upper part of the oesophagus is supplied by the recurrent laryngeal nerve and by sympathetic fibres from cell bodies in the middle cervical ganglion running in on the inferior thyroid arteries. The lower part receives fibres from the sympathetic trunks and greater splanchnic nerves, while the parasympathetic supply is from the vagus nerves which form anterior and posterior oesophageal plexuses on the respective surfaces. These plexuses, which form a wide-meshed network that encircles the tube below the level of the lung roots, are essentially parasympathetic and their fibres become collected together over the last few centimetres of the thoracic oesophagus as the anterior and posterior vagal trunks (p. 334). The anterior trunk contains predominantly left vagal fibres and the posterior mainly right fibres, but both trunks have fibres from both vagi.

The *motor* supply is from the vagus, from cell bodies in

the nucleus ambiguus for the upper striated-muscle part, and from the dorsal motor nucleus with relay in plexuses in the wall for the lower visceral muscle part. The glands also receive secretomotor fibres from the vagus but these are derived from cell bodies in the inferior salivary nucleus. There are also afferent fibres in the vagi with cell bodies in the inferior vagal ganglia, but pain fibres appear to run with both the vagal and the vasomotor sympathetic supply, since (like cardiac pain) oesophageal pain can be referred to the neck, arm and thoracic wall.

Structure

The muscular wall consists of an inner circular and an outer longitudinal layer which are of skeletal muscle in the upper third and visceral muscle in the lower two-thirds of the tube. There is no sharp line of demarcation between these two areas; there is considerable overlap of the two types of muscle. The skeletal muscle provides rapid contraction so that the bolus is quickly passed well into the oesophagus, and the larynx may safely open to resume breathing. Except for the short intra-abdominal segment, there is no serous covering of the tube. The mucous membrane is thick and in the collapsed state thrown into longitudinal folds. There is a thick muscularis mucosae. The surface epithelium of the mucous membrane is stratified squamous. The mucosa contains scattered lymphoid follicles. In the submucosa are mucous glands that are rather sparse and found for the most part at the upper and lower ends of the tube. The outer longitudinal layer of muscle is attached by fibrous strands to the midline ridge on the back of the lamina of the cricoid cartilage, and to the arytenoid cartilages. The inner circular layer is in direct continuity with the circopharyngeus muscle (p. 488). Although there is no anatomical thickening of muscle at the lower end of the oesophagus, the last 5 cm or so (2 in) undoubtedly acts as a physiological sphincter.

Surgical approach

The cervical part of the oesophagus is approached in the neck by opening up the interval between the trachea and the carotid sheath. In the thorax, a long length of oesophagus is readily accessible on the right side in front of the vertebral column, especially after transecting the azygos arch (Fig. 4.14). The posterior intercostal vessels and thoracic duct are at risk when mobilizing the oesophagus posteriorly. The lower part is more easily approached from the left side, above the diaphragm (Fig. 4.15) in the interval between the heart in front and the aorta behind.

LYMPH NODES OF THE THORAX

In the posterior mediastinum the nodes are arranged in series with those of the abdomen. The visceral *preaortic nodes* lie in front of the aorta and drain the middle reaches of the oesophagus. The somatic *para-aortic nodes* lie alongside the aorta and extend laterally into the posterior intercostal spaces, where they are known as the *posterior intercostal nodes*. They drain the parietes (intercostal spaces). The anterior ends of the intercostal spaces drain into *parasternal nodes* along the *internal thoracic artery*; they may become involved in cancer of the breast, and drain directly into the brachiocephalic veins.

The lower members of the parasternal group lie on the diaphragm between pericardium and xiphisternum (*anterior diaphragmatic nodes*). The lower members of the para-aortic group in the posterior mediastinum likewise lie on the diaphragm forming the *posterior diaphragmatic group*. In addition a *middle diaphragmatic group* lies on each dome of the diaphragm; they drain from the extraperitoneal areolar tissue beneath the diaphragm and, on the right side, from the superficial part of the bare area of the liver.

The upper members of the posterior intercostal group drain into the thoracic duct or into the right lymphatic duct (see below); the lower (intercostal and diaphragmatic) members drain into a **descending intercostal trunk** that passes downwards to join the cisterna chyli in the aortic opening of the diaphragm.

Heart and lungs drain into the *tracheobronchial lymph nodes*, which lie around the trachea and its bifurcation. These send their efferents to a right and left **mediastinal lymph trunk**, which may join the thoracic duct but usually open directly into the brachiocephalic vein of their own side.

There are thus three upgoing lymph channels on each side, namely the parasternal alongside the sternum, the thoracic duct and right lymphatic duct alongside the vertebrae (these drain the thoracic wall) and between them the mediastinal lymph trunks alongside the trachea (these drain lungs, midpart of oesophagus, and heart). All six trunks communicate freely with each other.

THORACIC DUCT

This, the longest lymphatic channel, commences at the upper end of the cisterna chyli, on a level with the body of T12 vertebra between the aorta and the azygos vein. From behind the right crus it passes upwards to the right of the aorta and comes to lie against the right side of the oesophagus. Inclining up to the left, alongside the aorta, it passes behind the oesophagus to reach its left side at the superior mediastinum. It lies anterior to

the intercostal branches of the aorta. Passing now vertically upwards it finally arches forwards across the dome of the left pleura to enter the point of confluence of the left internal jugular and subclavian veins (Fig. 4.12). It normally divides into two or three separate branches, all of which open at the angle between these two veins. There are no valves at the termination, and blood flows to and fro in the duct as pressures alter with respiratory movements. At autopsy it is common to find the terminal inch or two of the thoracic duct full of blood, because the last of the valves, of which there are many, is a little proximal to the venous junction.

Commencing with the accumulated lymph from the lower half of the body, the duct receives in its course through the thorax lymph from the left posterior intercostal nodes (posterior half of the left thoracic wall). In the neck it receives the left **jugular** and **subclavian lymph trunks** and thus finally comes to drain all the lymph of the body except that from the right arm and the right halves of thorax and the head and neck.

Lymph from the posterior right thoracic wall enters the **right lymphatic duct**. The right upper limb drains into the right subclavian trunk and the right side of the head and neck drains into the right jugular lymph trunk. These three trunks may join together and open into the commencement of the right brachiocephalic vein or they may remain separated and open independently into the great veins (jugular and subclavian).

AZYGOS SYSTEM OF VEINS

The thoracic wall and upper lumbar region are drained by the posterior intercostal and lumbar veins into the azygos veins. These consist of longitudinal trunks on right and left sides, similar to the posterior cardinal veins of the embryo. There is a single trunk on the right. On the left side the posterior cardinal vein disappears (p. 45) and is replaced by longitudinal veins that persist from the embryonic prevertebral venous plexuses; these are the hemiazygos veins.

Azygos vein

This vessel represents the persistent right posterior cardinal vein of the embryo. Thus it begins embryologically at the inferior vena cava just above the renal veins, but this part is usually an avascular fibrous cord. The union of the ascending lumbar vein with the subcostal vein of the right side is the functional (blood-containing) commencement of the azygos vein. The vessel goes through the aortic opening of the diaphragm under shelter of the right crus (Fig. 4.33) and passes upwards lying on the sides of the vertebral bodies, on a

plane posterior to that of the oesophagus (Fig. 4.14). Descent of the heart and pericardium in the embryo caused the right posterior cardinal vein to arch over the right bronchus. This the azygos vein does at the level of T4 vertebra and passing forward of the oesophagus the vessel enters the superior vena cava. It receives the lower eight posterior intercostal veins and at its convexity the superior intercostal vein joins it. It receives the bronchial veins from the right lung and some veins from the middle third of the oesophagus. The two hemiazygos veins join it at the levels of T8 and 9 vertebrae.

Hemiazygos veins

These two veins lie longitudinally on the left side of the bodies of the thoracic vertebrae. They may communicate with each other, but characteristically drain separately from their adjoining ends behind the oesophagus into the azygos vein. They receive the lower eight posterior intercostal veins, four each. The inferior vein is the **hemiazygos vein**, and the superior one is the **accessory hemiazygos vein**. The latter receives the bronchial veins from the left lung and some veins from the middle third of the oesophagus.

THORACIC SYMPATHETIC TRUNK

Lying on the necks of the ribs, just lateral to their heads, and anterior to the intercostal vessels and nerves, is the thoracic part of the sympathetic trunk (Fig. 4.3). It is described as possessing 12 ganglia, one for each intercostal nerve, but characteristically there are fewer, the result of fusion of adjacent ganglia. Thus the first ganglion is commonly fused with the inferior cervical ganglion to form the *cervicothoracic (stellate) ganglion*. It is simplest, however, to describe them as though they consisted of 12 discrete ganglia. Each receives a white ramus from its corresponding spinal nerve, and this emerges from the anterior ramus of the nerve. After relay in the ganglion a postganglionic grey ramus is given to each thoracic nerve, and this usually lies medial to the white ramus (Fig. 1.21, p. 30).

The heart is supplied with sympathetic fibres from the cervical and upper thoracic ganglia through the cardiac plexus (coronary and cardiac parts, p. 259). The pulmonary part supplies the lungs (p. 286). The trachea and oesophagus receive branches from trunk ganglia, but note that the oesophageal plexuses (p. 278) are vagal (parasympathetic) plexuses.

The splanchnic nerves, three in number, come from the lower eight ganglia. The *lowest*, or **least splanchnic nerve** leaves the twelfth ganglion; the **lesser splanchnic**

nerve comes from the tenth and eleventh. The **greater splanchnic nerve** is formed by branches from the fifth to the ninth ganglia. Each pierces the crus of its own side to relay in the coeliac ganglia (p. 365).

The thoracic trunk is continued upwards over the neck of the first rib as the cervical sympathetic trunk. It crosses the neck of the first rib well on the medial side, near the head. The main part of the first thoracic nerve, passing out of the thorax into the neck to join the brachial plexus, crosses the neck of the first rib more laterally. Between the two at this level lie the supreme intercostal vein medially, and the superior intercostal artery laterally. Classical description of the ganglia consists of describing the first thoracic ganglion as lying below the neck of the first rib, and the inferior cervical ganglion lying in the root of the neck just above the neck of the rib, posteromedial to the vertebral artery. More often than not, however, these two ganglia are fused into a single mass, the *cervicothoracic* or *stellate ganglion*, overlying the neck of the first rib (Fig. 4.5). It is very variable in size, and may measure as much as 2 cm in length and 0.5 cm in diameter.

The thoracic trunk is continued downwards into the abdomen by passing behind the medial arcuate ligament of the diaphragm, lying on the front of the fascia of the upper part of the psoas muscle. It makes an abrupt step forwards from the neck of the eleventh (or even the tenth) rib to the front of the body of L1 vertebra, and this part of the trunk is very slender.

Cervical sympathectomy

In the cervical approach (p. 32) from above the clavicle, scalenus anterior and the suprapleural membrane are divided (avoiding damage to the phrenic nerve) and the subclavian artery is displaced downwards so that the pleura can be stripped off the vertebral column and adjacent parts of the ribs to expose the trunk. The second and third thoracic ganglia and the intervening trunk are removed. In the axillary approach the pleural cavity is entered through the bed of the third rib and the pleura incised over the trunk.

PART 8 PLEURA

Like peritoneum, the **pleura** is a membrane of fibrous tissue surfaced by a single layer of very flat cells (mesothelium) to make it slippery. It clothes each lung and lines the containing cavity.

The **parietal layer** of the pleura lines the thoracic

wall (rib cage), to which it is attached by areolar tissue named the *endothoracic fascia*. It covers the thoracic surface of the diaphragm, from which it ascends over the pericardium to cover the mediastinum and to cling to the suprapleural membrane at the thoracic inlet. This is one continuous sheet. From its mediastinal layer a cuff of membrane is projected around the lung root and passes on to invest the surface of the lung. This is the **visceral layer** of the pleura; it extends into the depths of the interlobar clefts. The pleural cavity is a completely closed space. The visceral pleura on the lung surface is in contact with parietal pleura, but the anterior and inferior reflexions of the parietal pleura extend further than the lung edge, to allow space for lung expansion. In these situations the costal parietal pleura is in contact anteriorly with mediastinal and inferiorly with diaphragmatic parietal pleura.

The function of the pleura, like that of pericardium and peritoneum, is to provide two frictionless surfaces between a mobile structure and the containing walls of its cavity; the surfaces are lubricated by a thin film of tissue fluid. The cuff of pleura projected around the lung root is too big for it, as a coat cuff is too big for the wrist. It hangs down below as an empty fold, the *pulmonary ligament*, an ill-chosen name for it has nothing to do with the lung and is not a ligament. It provides 'dead space' into which the lung root descends with descent of the diaphragm, and, more importantly, allows for expansion of vessels in the lung root, especially the inferior pulmonary vein, which is always the lowest structure in the root. Large veins always have 'dead space' near them (e.g. to the right of the superior vena cava, and in the femoral canal alongside the femoral vein).

Outside the pleura, and lining the thoracic wall, is a layer of loose areolar tissue similar to the transversalis fascia of the abdomen, which binds the parietal pleura to the inner side of the chest wall and transversus thoracis group of muscles where these exist. This loose areolar tissue has been named the *endothoracic fascia*; it is almost unworthy of anatomical description, being nowhere membranous, and consisting merely of the fibrous tissue that attaches the pleura to the chest wall. A similar layer binds the pleura to the diaphragm. No such arrangement exists on the fibrous pericardium. Here the slippery pleura is thin, and so adherent that the two cannot be separated.

Nerve supply

The parietal pleura is supplied by somatic nerves, namely the intercostals, segmentally in zones on its costal extent; the diaphragmatic pleura is supplied by the phrenic nerve over the domes, and by intercostal

nerves around its periphery. The mediastinal pleura is supplied by the phrenic nerve. The visceral pleura has only an autonomic (i.e. vasomotor) supply—it is insensitive to ordinary stimuli.

Surface markings

The parietal pleura lines the costal walls of the thorax; seen from in front its lateral surface marking is the horizon of the thoracic cage (Fig. 4.30). It projects above the medial third of the clavicle for nearly 3 cm (over an inch). This convexity, well seen in radiographs of the chest, is due to the obliquity of the thoracic inlet (Fig. 4.9). The neck of the first rib lies well above the clavicle, and the surface marking of the dome of the pleura (and the apex of the lung) is merely the projection of the inner border of the first rib. There is normally no encroachment of lung or pleura above the oblique plane of the thoracic inlet except for a minor amount of bulging above the subclavian groove, beneath the suprapleural membrane just in front of the neck of the first rib (Fig. 4.5).

Tracing the pleura now (Fig. 4.30) from behind the sternoclavicular joint, downwards behind the sternum and around the costodiaphragmatic gutter, there is a point to be noted at each of the *even-numbered ribs* (2, 4, 6, 8, 10, 12) as follows. The line of pleural reflexion slopes downwards from the sternoclavicular joint to meet its fellow at the *second* rib level, that is, at the sternal angle. Lying together or even overlapping, with the right pleura perhaps to the left of the midline they pass vertically behind the sternum down to the *fourth* costal cartilage. Here the right pleura continues vertically, but the left arches out and descends lateral to the border of the sternum, half-way to the apex of the heart. Each turns laterally at the *sixth* costal cartilage, and passing around the chest wall crosses the midclavicular line at the *eighth* rib, and the midaxillary at the *tenth* rib. This lower border is the **costodiaphragmatic recess**; it falls somewhat short of the costal margin between sternum and midaxillary line. It crosses the *twelfth* rib at the lateral border of erector spinae and passes in horizontally to the lower border of the *twelfth* thoracic vertebra. There is thus a triangle of pleura in the costovertebral angle below the twelfth rib, behind the upper pole of the kidney, a fact to be noted in incisions and wounds in this region (Fig. 5.46, p. 367).

Pleural aspiration and drainage

The anatomy of an intercostal space determines the route for removing fluid (or air) from the pleural cavity. Aspiration needles or drainage tubes are passed

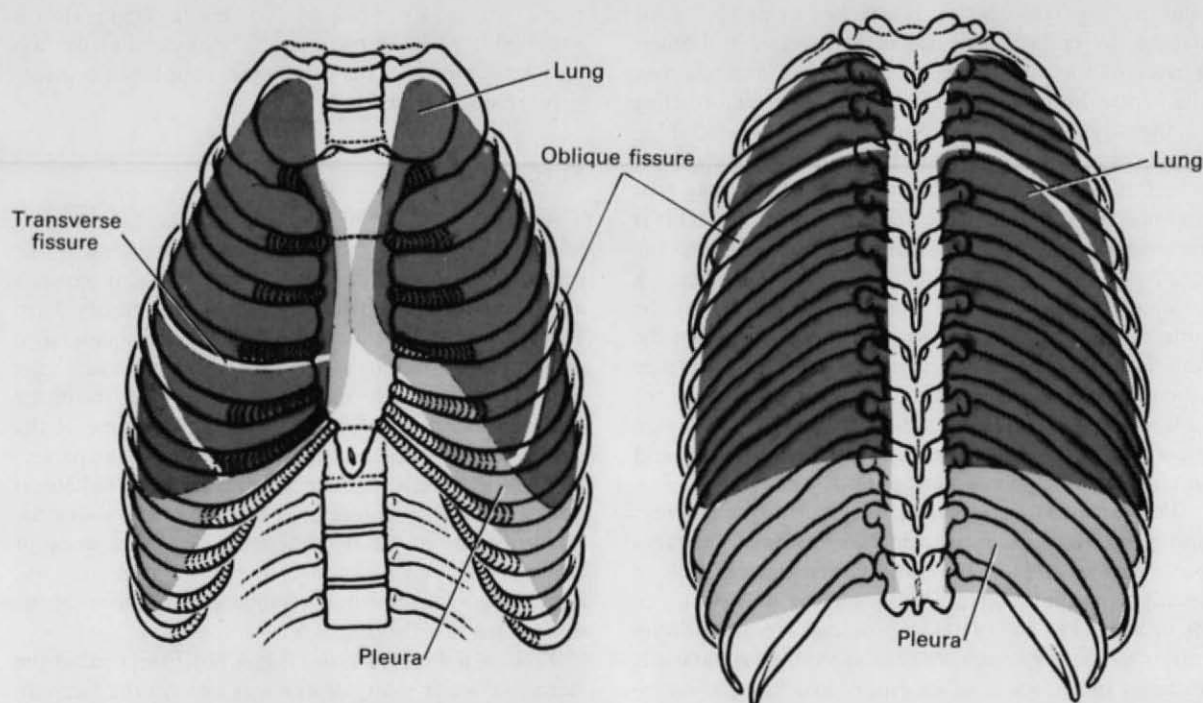


Fig. 4.30 Surface markings of the lungs and pleurae.

through the chest wall close to the upper border of a rib (lower part of an intercostal space) to avoid the vessels and nerve which course along the lower border of a rib (upper part of a space) (Fig. 4.4). The choice of space may be determined by the localization of fluid, e.g. a walled-off abscess, but for general purposes the fourth space in or just in front of the midaxillary line is often chosen. A needle, trocar and cannula or drainage tube inserted here is not near any major structure and is high enough to avoid the dome of the diaphragm.

PART 9 LUNGS

Each **lung**, consisting of two lobes on the left and three on the right, lies within its own side of the thoracic cavity and is surrounded by the visceral layer of the pleura. Each has a principal or main bronchus, one pulmonary artery and two pulmonary veins, all of which undergo subdivisions within the lung substance, together with bronchial vessels, nerves and lymphatics. The region where the lung is connected to the mediastinum, largely by the bronchus and pulmonary

vessels, is the root of the lung, and the region of the lung where these structures enter or leave is the hilum.

The lung surface is mottled, and in colour is pink or grey according to the atmosphere in which it has lived. It is crepitant to the touch.

The lung conforms to the shape of the cavity which contains it. It has a convex costal surface and a concave diaphragmatic surface, separated from each other by a sharply-angled inferior border. The posterior border of each lung is generously rounded to fit the paravertebral gutter, and is continued up to the convex apex. The anterior border is thin and sharp; on the left side the lower part of this border is deeply concave — the *cardiac notch*. The mediastinal surfaces differ somewhat. On the left side the cardiac notch is seen to be the anterior margin of a deep concavity produced by the pericardium in front of the hilum; the arch and ascending aorta make a deep groove on the lung surface around the hilum. Above the aortic arch are vertical impressions made by the subclavian artery and (behind the artery) the oesophagus. On the right the cardiac impression is much shallower; a groove for the azygos vein curves over the hilum to meet the impression made by the superior vena cava. Above the azygos arch and behind the vena cava are grooves for the trachea and oesophagus. The apices are grooved by the subclavian arteries

(Figs 4.5 and 4.12). The other relations of the apices are best studied with the root of the neck (p. 442).

Lung roots

When a lung is removed by a clean cut at the side of the mediastinum, the cut surface on the mediastinum is the lung root; the corresponding cut surface on the lung is the hilum. The left and right lung roots are similar but not identical.

In the **left lung root** (Fig. 4.15) the upper part is occupied by the left pulmonary artery lying within the concavity of the arch of the aorta. Below and behind it is seen the left bronchus as it slopes downwards from the bifurcation of the trachea. There are two pulmonary veins, one in front of and the other below the bronchus. These structures are enclosed in a sleeve of pleura—a sleeve that is too big for the lung root, as a coat cuff is too big for a wrist, so that it hangs down in an empty fold, the pulmonary ligament. It is, of course, not a ligament, neither is it concerned with the lung; it provides the necessary freedom or 'dead space' for the structures of the lung root. Its two layers separate on descent of the lung root in inspiration and on enlargement of the pulmonary veins during increased pulmonary blood flow.

In the **right lung root** (Fig. 4.14) the general arrangement of structures is similar to that on the left, but the bronchus to the upper lobe (the *eparterial bronchus*) and the branch of the pulmonary artery to the upper lobe leave the main bronchus outside the lung. Thus the upper lobe bronchus and its accompanying artery are found above the level of the main bronchus in the root. The two pulmonary veins are disposed as on the left side, in front of and below the main bronchus. The root of the right lung lies within the curve of the azygos vein and is surrounded by a sleeve of pleura with a dependent pulmonary ligament, as on the left.

In addition to the above large structures, each root contains bronchial vessels, autonomic nerves and lymph nodes and channels (p. 285).

Pulmonary arteries

The *left pulmonary artery* (p. 372) attached to the under surface of the aortic arch by the ligamentum arteriosum, quickly spirals over the top of the left bronchus to reach the back of the bronchus and enter the hilum of the lung. The *right pulmonary artery*, longer than the left, passes below the carina anterior to the oesophagus, and at the lung root is held anterior to the right main bronchus by the upper lobe bronchus (Fig. 4.31). It gives off its branch to the upper lobe and then enters the hilum.

For pulmonary artery catheterization see page 272.

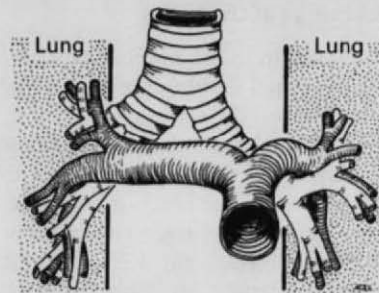


Fig. 4.31 Bifurcation of the pulmonary trunk and the pulmonary arteries. The trunk divides in front of the left main bronchus. The left pulmonary artery spirals over the main bronchus to descend behind the lobar bronchi. The right pulmonary artery crosses below the tracheal bifurcation (in front of the oesophagus), and its descent behind the lower lobe bronchus is delayed because the artery is held anterior at the lung root by the upper lobe bronchus.

Fissures

The **oblique fissure** (Figs 4.35 & 4.36) extends from the surface of the lung to the hilum and divides the organ into separate upper and lower lobes which are connected only by the lobar bronchi and vessels. In 50% of lungs the fissure may not be complete. On the right lung a **horizontal fissure** (Fig. 4.35) passes from the anterior margin into the oblique fissure to separate a wedge-shaped middle lobe from the upper lobe. The visceral pleura, clothing the surface of the lung, extends inwards to line the depths of the fissures. The middle lobe of the right lung is completely separate from the upper lobe in only about one-third of individuals; in the remainder the fissure separating it from the upper lobe is incomplete or even absent (10%). On the left lung the lowest and most medial part of the upper lobe that overlaps the front of the pericardium is the lingula and forms the boundary of the cardiac notch; it corresponds to the middle lobe of the right lung but is never separate.

The oblique fissure of each lung makes a slippery surface between the two halves. This promotes easier and *more uniform* expansion of the whole lung. Movements of the chest wall and diaphragm are of greater range towards the base of the lung. The great elasticity of the lung encourages equal expansion throughout, but the apex is greatly helped to expand by the lower part of the upper lobe being so near the diaphragm and lower chest wall. Descent of segments 4 and 5 improves expansion of segments 1, 2 and 3 (Figs 4.35, 4.36). Thus the *obliquity* of the great fissure is functional, for if the lung were divided into two halves by a horizontal fissure this would have less effect on apical expansion.

Surface markings of the lungs

The hilum of each lung lies approximately behind the third and fourth costal cartilages at the sternal margin, and level with T5, 6 and 7 vertebrae.

On upper costal walls and the supraclavicular region, the surface markings of the lungs coincide with those of the pleura (Fig. 4.30). The anterior border of the right lung falls very little short of the pleura, lying within the lateral margin of the sternum; that of the left lung in contrast curves laterally to uncover the area of superficial cardiac dullness from the fourth costal cartilage out to the apex beat in the fifth intercostal space just medial to the midclavicular line. From these points the lower border of the lung lies nearly horizontally around the chest wall, but *two ribs higher than the pleural reflexion*, i.e. in the midclavicular line at the sixth rib, midaxillary line at the eighth rib, and at the lateral border of erector spinae at the tenth rib.

The oblique fissures of each lung are indicated by a line joining the spine of T3 vertebra (which is opposite the posterior end of the fifth rib) to the sixth rib in the midclavicular line. More simply, this is approximately the line of the fifth rib, or level with the vertebral border of the scapula when the arm is fully abducted above the head. On the right the fourth costal cartilage overlies the horizontal fissure between the upper and middle lobes; continued horizontally this line meets the oblique fissure in the midaxillary line.

Lobar and segmental bronchi

Because the left lung grows into a smaller cavity than the right, the way bronchi divide to supply segments of lung is not identical on the two sides, although there are close similarities.

From the bifurcation of the trachea (p. 260) each **main bronchus** (Figs 4.32–4.34) passes downwards and laterally to enter the hilum of the lung. They are approximately 5 cm (2 in) long, but the right is slightly shorter and more vertical than the left. At the bifurcation an anteroposterior internal ridge, the *carina*, lies to the left of the midline, so that foreign bodies that fall down the trachea are more likely to enter the right bronchus.

Each main bronchus gives rise to **lobar bronchi** (Fig. 4.32) that supply the lobes of the lung. The right main bronchus gives off the upper lobe bronchus outside the hilum and ends within the hilum by dividing into middle and lower lobe bronchi. The left main bronchus divides within the hilum into upper and lower lobar bronchi. The tissues of the bronchi are supplied by the bronchial arteries. The

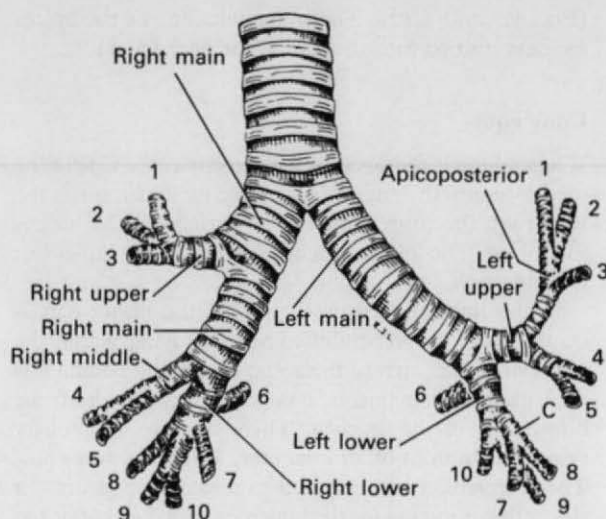


Fig. 4.32 Main, lobar and segmental bronchi. The main and lobar bronchi are named; the segmental bronchi are given their numbers as in the list below, and on the left 7 and 8 share a common stem (C).

veins of the right main bronchus drain to the azygos vein and those of the left to the accessory hemiazygos vein.

Each lobar bronchus gives rise to further branches, the **segmental bronchi** (Fig. 4.32), for each segment of the lung. There are typically 10 **bronchopulmonary segments** in each lung and therefore 10 segmental bronchi are to be expected. Ten individual segmental bronchi can usually be distinguished on the right, but on the left it is usual for one or more segmental bronchi to share a common stem. Each lung segment is roughly pyramidal in shape, with its apex towards the hilum and base towards the surface of the lung. The bronchopulmonary segments are given the same names and numbers as the segmental bronchi, which are listed as follows:

Right lung

Upper lobe

1. Apical
2. Posterior
3. Anterior

Middle lobe

4. Lateral
5. Medial

Lower lobe

6. Apical (superior)

Left lung

Upper lobe

1. } Apicoposterior
2. }
3. Anterior

4. Superior lingular
5. Inferior lingular

Lower lobe

6. Apical (superior)

- | | |
|---------------------------|-----------------------------|
| 7. Medial basal (cardiac) | 7. } Medial basal (cardiac) |
| 8. Anterior basal | 8. } Anterior basal |
| 9. Lateral basal | 9. } Lateral basal |
| 10. Posterior basal | 10. } Posterior basal. |

From the above it can be seen that the bronchi and segments of the two lungs are very similar. Both lower lobes have five segmental bronchi and segments, the only difference being that on the left the medial basal segment (7) is small because the pericardial excavation suppresses this part of the lung and its bronchus usually arises by a common stem with the anterior basal bronchus (8), thus sometimes giving rise to the erroneous impression that it is absent. The upper lobe of the right lung has three segments and the middle lobe two, and each has its own bronchus. The upper lobe of the left lung has five segments, the two lowest (lingular) corresponding to the two of the middle lobe of the right lung, and it is the rule for the uppermost two to be supplied by bronchi that have a common apicoposterior stem. Note that the lingular part of the left upper lobe has segments called superior and inferior, whereas in the middle lobe of the right lung the adjectives are lateral and medial; otherwise the names on the two sides are identical.

Two other facts about the branching of the bronchi should be emphasized. On the right the upper lobe bronchus arises high up on the side of the main bronchus outside the hilum, and on both sides the apical segment of the lower lobe is supplied by a bronchus (6) which is the highest to arise from the

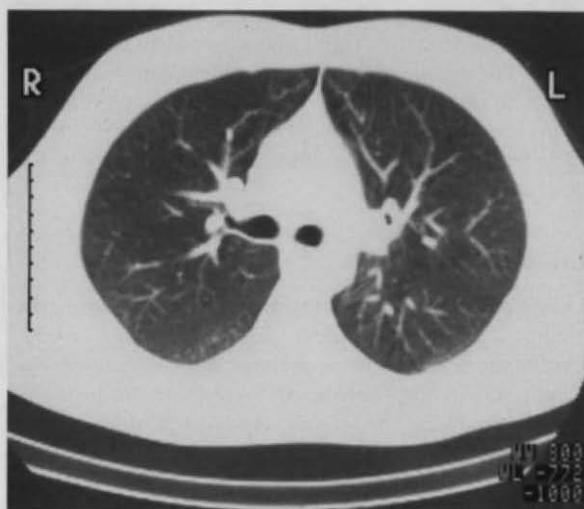


Fig. 4.34 CT scan, at the same level as Figure 4.33 but at a different image setting to show pulmonary vessels which are not visualized at the settings required to show mediastinal structures. The translucencies near the centre are the two main bronchi.

posterior surface of the bronchial tree, so that when lying on the back it is the highest bronchus into which fluid can gravitate.

Blood supply

The bronchial tree receives its own arterial supply by the *bronchial arteries*. There are usually three: two on the left which are direct branches from the aorta, and one on the right coming from the third right posterior intercostal artery. They supply the bronchi from the carina to their ultimate ramifications (respiratory bronchioles) and nourish also adjacent lymph nodes and the visceral pleura. The *bronchial veins* fall into a superficial system draining from the hilar region and visceral pleura into the azygos vein on the right and the accessory hemiazygos on the left, and a deep system from the deeper lung substance draining to a main pulmonary vein or directly into the left atrium (thus mixing venous with arterial blood). The *alveoli* contain within their walls a rich capillary plexus which is fed with deoxygenated blood by the *pulmonary artery*. The pulmonary artery divides with the bronchi; every bronchus is accompanied by a branch of the artery. The artery supplies no bronchus but it does supply the alveoli, giving them all they need except oxygen, of which they have more than enough. There is some anastomosis between the bronchial and pulmonary arteries at

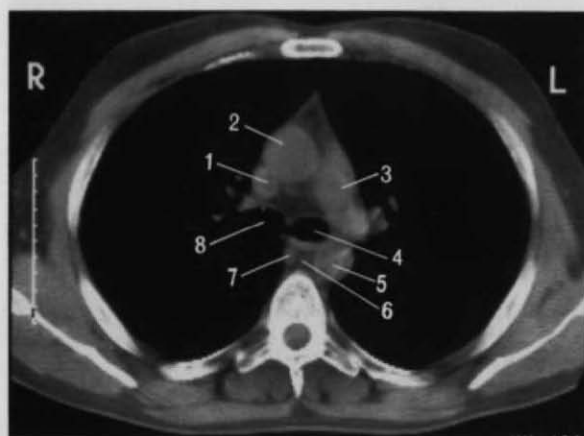


Fig. 4.33 CT scan, just below the level of the tracheal bifurcation, viewed from below: 1 — superior vena cava, 2 — ascending aorta, 3 — left pulmonary artery, 4 — left main bronchus, 5 — thoracic aorta, 6 — oesophagus, 7 — azygos vein, 8 — right main bronchus.

precapillary level, though peripherally there is some overspill of bronchial capillaries into the alveolar capillaries. The *pulmonary veins* are formed from tributaries which do not closely follow the bronchi but tend to run in the intersegmental septa. Two pulmonary veins leave each hilum, one from above and one from below the oblique fissure.

Lymph drainage

Lymphatic channels run towards the hilum, from the pleura along the bronchi and pulmonary artery. Lymphatic tissue occurs as isolated follicles beneath the pleura and in the mucous membrane of the bronchi, usually straddling the bifurcations. Lymph nodes in the hilum lie just within and just without the lung substance. These *hilar nodes* drain to the tracheo-bronchial group, thence upwards by mediastinal lymph trunks to the brachiocephalic veins.

Nerve supply

The pulmonary plexus (from the cardiac plexus — p. 259) at the hilum of each lung sends its autonomic fibres along the bronchial tree. The parasympathetic fibres (vagus nerve) are afferent (cell bodies in the inferior ganglion) and efferent (cell bodies in dorsal

nucleus, with relay in the bronchial mucosa). They provide the afferent fibres for the cough reflex (p. 503), important for clearing excess secretions and inhaled substances from the tracheobronchial tree; the receptors are unmyelinated endings in the epithelium. The vagi also provide the pathway for the response to bronchial stimulation by a catheter passed down the trachea (one of the tests for brainstem death — p. 616). Included among the afferent fibres are those subserving pain. The vagal efferents are motor to the smooth muscle of the bronchi and the pulmonary arterioles, shutting both down for economy of effort. The sympathetic fibres relay in the upper four thoracic ganglia; their connector cells lie in the lateral horn of T2–6 segments of the cord. The sympathetic efferents are dilator to the pulmonary arterioles and to the bronchi, to accommodate the higher cardiac output and increased pulmonary ventilation that accompany 'storming the citadel'.

For the central control of respiration, see page 253.

Structure

Bronchi have smooth muscle and hyaline cartilage in their walls and are lined by the typical respiratory type of epithelium — pseudostratified columnar ciliated, with mucous glands. By successive divisions they

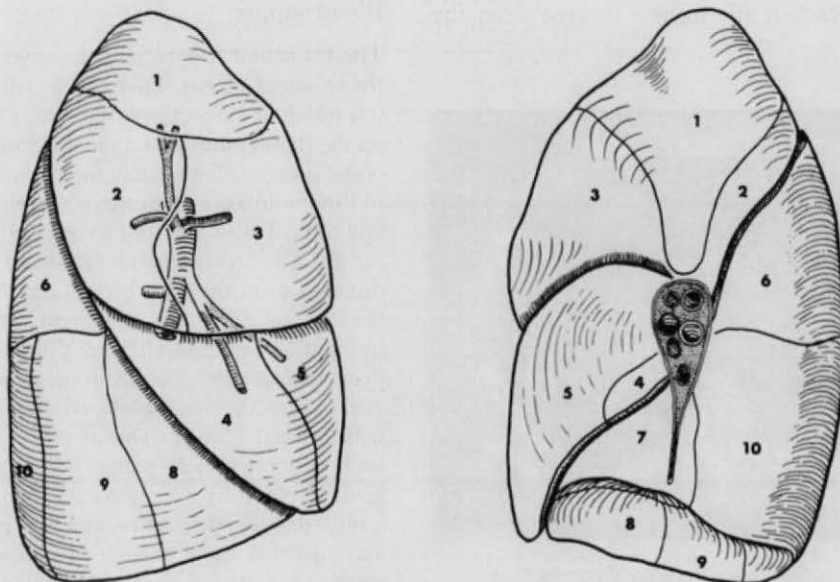


Fig. 4.35 Bronchopulmonary segments of the right lung, lateral and medial surfaces. Note the distribution of the upper and middle lobe bronchi and the posterior origin of the superior bronchus of the lower lobe (6).

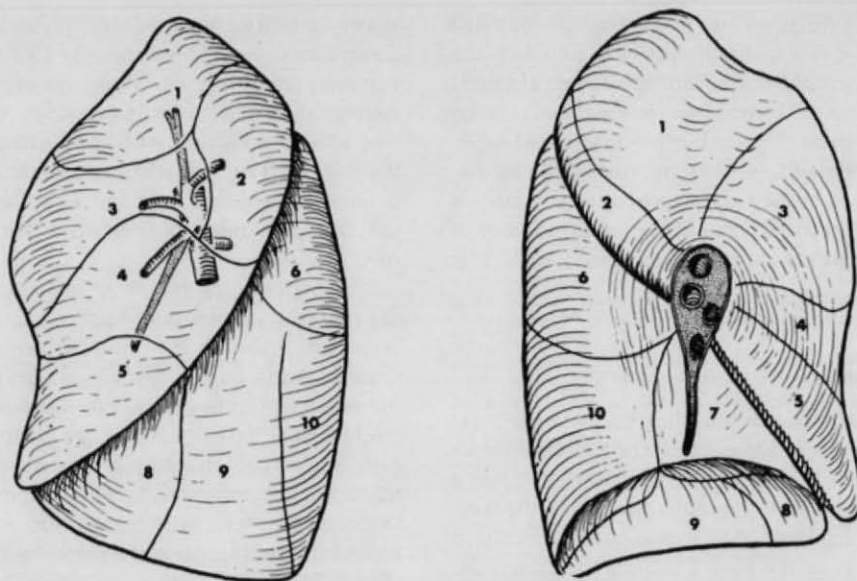


Fig. 4.36 Bronchopulmonary segments of the left lung, lateral and medial surfaces. Note the distribution of the lingular bronchi of the upper lobe and the posterior origin of the superior bronchus of the lower lobe (6), as in the right lung.

become smaller and smaller; when cartilage disappears (at a diameter of about 1 mm) bronchi become *bronchioles*. The more distal divisions of bronchioles, where cilia begin to disappear, are *respiratory bronchioles*, so called because some *alveoli* (air sacs) open off them. The bronchioles just proximal to respiratory bronchioles are rather confusingly called *terminal bronchioles*, but they are not the 'end of the line' as far as tubule division is concerned; they are the most peripheral bronchioles that do not bear any alveoli, and there are about 25 000 in each lung. There can be as many as 27 generations of divisions beyond the main bronchi; the first 19 are conducting airways, as far as terminal bronchioles, with no gaseous exchange, but often there are no more than five or six divisions before the terminal bronchioles are reached. Each terminal bronchiole with its subsequent branches constitutes a *lung acinus*. Beyond the respiratory bronchioles are the *respiratory ducts*, with many alveoli opening off them, and these continue into *alveolar ducts* which have a lining of cubical epithelium (but no cilia) and also many alveoli. Finally there are the *alveolar sacs* which become cubicalized into alveoli; the alveolar sacs may be likened to the central area of a room in a library or museum, with cubicles (alveoli) arranged round the sides (but also through the floor and ceiling!). Do not confuse alveolar ducts, alveolar sacs and alveoli.

The walls of the alveoli contain capillaries and various cells such as fibroblasts, macrophages and mast cells. The lining of the alveoli consists of two kinds of epithelial cells. The commonest (95%) are the *squamous cells*, flattened like vascular endothelium and sometimes called pneumocytes type I, through which gaseous exchange can occur. The other 5% are the *secretory cells* (type II) containing the characteristic whorl-like lamellar bodies with a high phospholipid content; when discharged from the cell they produce the surfactant effect (reducing surface tension).

Development

Each lung develops from a bud at the lower end of the laryngotracheal tube that grows down from the floor of the primitive pharynx (Fig. 1.29, p. 37). These epithelial (endodermal) buds form only the epithelial part of the lung; the connective tissue, cartilage and muscle of the bronchial tree are derived from the surrounding mesoderm. By the fifth month the lung has a glandular appearance, with clumps of epithelial cells and hardly any recognizable lumina, but the cell groups become expanded and lie adjacent to a multitude of capillaries so that by the seventh month there are sufficient alveoli to sustain a viable infant following premature birth at this time. Surfactant begins to be secreted about the sixth month.

In the fetus the lungs are not just a mass of collapsed air spaces but are full of fluid, largely secreted by the lungs but with a contribution from swallowed amniotic fluid. At the time of birth some is squeezed out by thoracic pressure and the rest escapes into blood capillaries and lymphatics, assisted by surfactant action. After birth there is no new development of any kind of bronchioles, but perhaps 90% of the adult number of alveoli are budded off during about the first 8 years of life.

Surgical approach

For *pneumectomy* the approaches on each side are similar, although the order in which the principal structures are dealt with may differ. On the left, after a posterolateral thoracotomy through the bed of the sixth rib, the lung is displaced downwards and forwards so that, after visualizing the pleura behind the hilum, the vagus can be divided distal to the recurrent laryngeal branch, and the pulmonary artery divided distal to the ligamentum arteriosum. This is followed by division of the upper pulmonary vein with the lung displaced backwards, and the lower pulmonary vein and the main bronchus with the lung pushed forwards again. The nearness of the aortic arch may make closure of the bronchus difficult.

On the right the pleura is incised in front of the hilum, and the upper pulmonary vein and the pulmonary artery are divided first, then the lower vein is divided with the lung reflected forwards, and finally the main bronchus is divided working from the front again. The arch of the azygos vein is preserved if possible since it affords collateral circulation if the superior vena cava is obstructed. The latter may have to be displaced forwards to allow satisfactory ligation of the pulmonary artery.

PART 10 OSTEOLOGY OF THE THORAX

ARTICULATED THORACIC SKELETON

Study the general features in an articulated skeleton (Fig. 4.30), remembering that cartilage cannot be preserved dry. Make allowances for 'costal cartilages' that may be distorted. The cage is convex, narrow above and below like a barrel, but flattened from front to back. In conformity with the general convexity of the thoracic wall the first rib has an upper surface and a

sharp external border; its pleural surface looks downwards, instead of inwards like the others. The vertebral column projects into the cage, leaving a deep paravertebral gutter on either side. A cross-section is shaped like a kidney, with the vertebral body making the hilum. The ribs slope down from the vertebral column towards the sternum at an angle of 45°; *note this*, and remember it later when handling individual ribs.

The angles of the ribs show as a line of ridges, one at the posterior convexity of each rib, lateral to the transverse processes of the thoracic vertebrae. An angle scarcely exists on the first rib, where it coincides with the tubercle, but from here down the angle lies progressively farther laterally. The ridge at the angle lies vertically across the obliquity of the rib (Fig. 4.38). It is made by the attachment of the thoracolumbar fascia that encloses erector spinae; this muscle is widest behind the twelfth rib and narrows as it passes upwards (Fig. 6.74, p. 545).

The term 'angle' always refers to the *posterior* angle of a rib (Fig. 4.38). There is what might be called unofficially an anterior 'angle', but this is much less pronounced, and cannot be made out on every rib. It lies a few centimetres from the anterior extremity of the rib and consists of a low plateau, triangular in shape (apex up). It is for the origin of external oblique (hence absent from the upper four ribs) and is usually best seen on the sixth and seventh ribs (Fig. 4.37).

The anterior ends of the ribs fall progressively short of the midline from above down. The upper seven articulate with the sternum, by costal cartilages and these

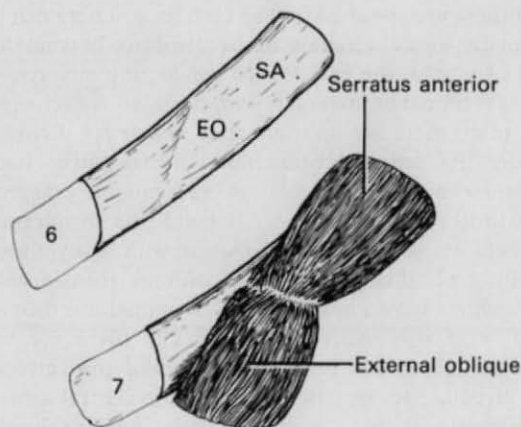


Fig. 4.37 Anterior ends of the sixth and seventh ribs and attachments of serratus anterior (SA) and external oblique (EO).

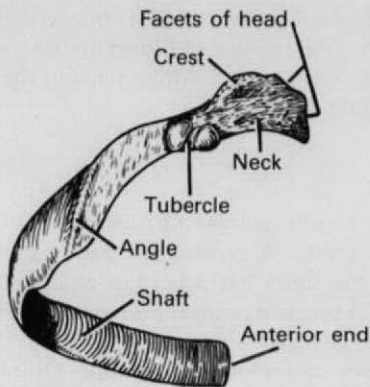


Fig. 4.38 Typical left rib, from behind (see p. 290).

seven cartilages become progressively longer from the first to the seventh. The upper three cartilages lie nearly horizontal, but below this the cartilages, themselves bent, pass progressively more obliquely upwards as they converge towards the lower end of the sternum (Fig. 4.30). The costal margin is made by the seventh to tenth cartilages. Below this the eleventh and twelfth ribs, each capped by an apex of cartilage, float free in muscles.

STERNUM

Like the ribs, most of the sternum is made of cancellous bone which throughout life is filled with haemopoietic marrow. The thin layer of compact bone on the surface is scored and perforated by multiple minute vessels. The main parts, manubrium and body, are connected by a secondary cartilaginous joint that normally never ossifies and contributes to movement of the ribs. The small third part, the xiphoid process, projects down from the lower end of the body.

The **manubrium** is a flat four-sided bone broader above than below (Fig. 4.5). Its upper margin is concave, the *jugular notch*, and this receives the interclavicular ligament. It is spanned by the investing layer of deep cervical fascia, attached to the anterior and posterior borders of the notch (p. 422). Each upper angle of the manubrium is scooped out into a concavity for the sternoclavicular joint. The articular surface, covered mostly by fibrocartilage rather than hyaline cartilage, lies in contact with the disc, while the capsule and synovial membrane are attached to the articular margin. Below the clavicular surface the lateral border is excavated for about 2 cm to receive the first costal cartilage (a primary cartilaginous joint). At the inferior angle is a 'demifacet', a small cartilage-covered area for

articulation (synovial) with the upper part of the second costal cartilage. The inferior border of the manubrium is irregular and undulating; like the reciprocal upper border of the body it is coated with hyaline cartilage for the manubriosternal secondary cartilaginous joint. The anterior surface gives origin to pectoralis major alongside the lateral border, and more medially the tendon of sternocleidomastoid is attached; neither of these marks the bone. Posteriorly sternohyoid arises from a strip of bone alongside the clavicular margin while below this the origin of sternothyroid curves alongside the border of the bone below the facet for the first costal cartilage. Most of the posterior surface is bare. It lies against the lung margins in their pleural sacs, between which the left brachiocephalic vein touches the bone unless thymic remnants lie between.

The **body of the sternum** (gladiolus) carries articular facets along its lateral border. The lower part of the second costal cartilage articulates with a demifacet at the upper angle, making a synovial joint separate from that with the manubrium. Below this the border of the sternum is indented by five more cartilage-covered facets. These make single synovial joints with the costal cartilages (Fig. 4.2). The facets for the sixth and seventh costal cartilages may coalesce, especially in the female. Between the costal facets the lateral border of the sternum gives attachment to the anterior intercostal membrane and the internal intercostal muscle. The bone of this lateral border receives nutrient branches from the internal thoracic artery. Three faint ridges cross the anterior surface between the facets for the third, fourth and fifth cartilages; they mark the lines of fusion of adjacent sternebrae (p. 294). Pectoralis major arises widely from the anterior surface almost to the midline, and transversus thoracis arises from the posterior surface low down. From the posterior surface the weak sternopericardial ligaments pass, above and below, into the fibrous pericardium.

From the posterior margin of the body the xiphoid process (xiphisternum) projects downwards for attachment of the linea alba. It represents the unossified lower end of the body, with which it usually forms a symphysis. The process may ossify late in life.

The ossification of the sternum is dealt with on page 293, and its movements on page 252.

THORACIC CAGE

Note the multiple attachments of large sheets of muscle. Lateral to the sternum, pectoralis major has slips of origin from the upper six costal cartilages. Serratus anterior is attached to the upper eight ribs; the first rib has only a thin external border available, so the first

digitation spans the intercostal space along a fibrous band and is attached, with the second digitation, to a rough plateau which characterizes the second rib. The next digitations arise behind pectoralis minor, and the last four interdigitate with external oblique. So the eight digitations at the border of serratus anterior form a bold forward convexity. Pectoralis minor is attached to the third to fifth ribs (often also to the second) just in front of serratus anterior. External oblique arises from the anterior angles of the lower eight ribs; below serratus anterior it interdigitates with latissimus dorsi on the last four ribs. Rectus abdominis is attached to the anterior surfaces of the fifth to seventh costal cartilages and the lower border of the seventh. Lateral to this the lower borders of the last six costal cartilages receive the internal oblique. Transversus abdominis and the diaphragm interdigitate on the internal surfaces of the lower six costal cartilages. The serratus posterior muscles, lying on the thoracolumbar fascia, are inserted just lateral to the ridges at the posterior angles of their respective ribs—the second to fifth for the superior and the last four ribs for the inferior muscle. Between the angles and the transverse processes (i.e. the tubercles of the ribs) the iliocostalis and longissimus parts of erector spinae are attached, and a levator costae is inserted into the upper border of each rib just lateral to its tubercle. The scalene muscles and quadratus lumborum are attached to the thoracic cage, above and below; they belong with the intercostal muscles to the various layers of the body wall (p. 242). Their attachments will be noted in the study of the individual ribs. On the internal surfaces of the ribs the subcostal muscles lie in the paravertebral gutter, and the innermost intercostals lie in the lateral curve of the thoracic wall; each sheet widens from above down, but neither leaves any mark on the ribs. Between these sheets of muscle parietal pleura clothes the ribs and costal cartilages, except at the cardiac notch alongside the sternum behind the fifth and sixth left costal cartilages. Transversus thoracis is attached behind the medial ends of the second to sixth costal cartilages.

Surface markings

In the living the sternal angle is visible and palpable. The *second* costal cartilage can be easily felt at either side of the angle; the ribs must be counted down from here as the only certain guide to their numerical identification. The downward inclination of the ribs is indicated by the vertebral levels of the sternum. The jugular notch lies at the level of the upper border of the third, the sternal angle at the lower border of the fourth, and the lower end of the sternum at the lower border of

the eighth thoracic vertebrae. The surface markings of the heart (p. 266), pleura and lungs (p. 281 and 284) have already been studied. Movements of the ribs are considered on page 252.

RIBS

The first, eleventh and twelfth ribs are atypical (and perhaps the tenth). A **typical rib** from the middle of the rest of the series has a head, a neck and a shaft (Fig. 4.38). A tubercle projects posteriorly from the end of the neck. The shaft slopes down and laterally to an angle and then curves forward. The upper border of the shaft is blunt. Lateral to the angle (p. 288) the lower border projects down as a sharp ridge sheltering a costal groove. These features identify right from left ribs. They will be studied soon, but first lay the separate ribs in order on a table. The upper six lie reasonably flat, but the seventh to ninth show a degree of torsion at their angles that lifts the posterior end of each in a slope of 30° from the table. The tenth, eleventh and twelfth lie flat. The upper six ribs are bent into a tight curve, so that the end of the shaft has turned parallel with the neck of the rib (as in Fig. 4.7) to reach the front of the chest at a relatively short costal cartilage. The lower six ribs show an opening out of the curve, which in their case is completed by the long costal cartilages at the front of the chest.

The necks of the ribs are of equal length (except in the eleventh and twelfth), but the distance from tubercle to angle increases from above down as already noted in the articulated thoracic cage. This distance becomes equal to the neck length at the fifth and sixth rib. The tubercles of the typical ribs carry two oval facets. The medial one (for a synovial joint) of the upper six ribs is convex and projected backwards but in the next four ribs is flat and faces backwards and slightly downwards.

From all the above features it is easy to identify a rib of the upper, middle or lower part of the series.

A typical rib

The rib lies on the table in an unnatural position. *Pick it up* and hold it in its anatomical position; the shaft slopes down at 45° and the ridge at the angle is almost vertical. *The angle is the most posterior part of the rib. Study the rib in this position* (Fig. 4.38).

The **head** is bevelled by two articular facets that slope away from a dividing ridge. The lower facet is vertical; it articulates with the upper border of its own vertebra. The upper facet faces up to an overhanging

facet on the lower border of the vertebra above. Each makes a synovial joint, and the cavities are separated by a ligament attached to the ridge on the head. The capsule and synovial membrane of each separate joint are attached to the articular margin. The head projects forward a little as it expands from the neck. The radiate ligament is attached here, to the front of the head, and the sympathetic trunk lies in contact (Fig. 4.3), plastered in position by the adherent parietal pleura. Ribs *atypical as to the head* are the first, eleventh and twelfth (and perhaps the tenth); each makes a single synovial joint, with only its own vertebra.

The **neck** is flattened, with the upper border curving up into a thin, prominent ridge, the crest. The two laminae of the superior costotransverse ligament are attached to the crest, whence they pass up to the transverse process of the vertebra above (Fig. 4.1). The costotransverse ligament (p. 243) is attached between the back of the neck and the transverse process of its own vertebra. The front of the neck is clad in pleura. The neck of the rib inclines backwards when traced from head to tubercle.

The **tubercle** shows two smooth facets (Fig. 4.38). In the anatomical position they lie medial and lateral. The medial facet is covered with hyaline cartilage and makes a synovial joint with the transverse process of its own vertebra. Its shape and direction vary in upper and lower levels as already noted. The joint capsule and synovial membrane are attached to the articular margin. The lateral facet, smooth-surfaced, receives the lateral costotransverse ligament from the tip of its own transverse process. Ribs *atypical as to the tubercle* are the eleventh and twelfth (sometimes the tenth); no synovial joint exists here, only the ligament, and usually there is no tubercle on the rib.

The **shaft** slopes down and back to the angle and there twists forward in its characteristic curvature. The upper border is blunt. It gives attachment in its whole length to the external intercostal muscle from the rib above. Deep to this the internal intercostal muscle arises from the upper border between the anterior extremity and the angle, while between angle and tubercle the internal intercostal membrane is attached. Deep to this layer the subcostal and innermost intercostals sweep across the internal surface of the shaft, some of the fibres attaching themselves to the upper border. Elsewhere the internal surface of the shaft is in contact with parietal pleura. The lower border of the shaft is sharp, especially lateral to the angle, where it hangs down to produce a well-marked *costal groove*. Further forward the costal groove dies away, and the lower border of the rib becomes blunt like the upper border. The external intercostal muscle arises from the

sharp lower border and the internal intercostal is attached in front of the angle to the costal groove; anteriorly they are together attached to the blunt lower border. Between angle and tubercle the internal intercostal muscle is replaced by the posterior intercostal membrane. The neurovascular bundle lies just below its own rib, deep to the posterior intercostal membrane and muscle, high up in the space under shelter of the projecting sharp lower border of the rib. In front of the angle, the external surface of the shaft is bare, and serratus anterior plays over it on the upper eight ribs. The anterior end of the rib is excavated into a concave fossa; cancellous bone comes to the surface here. The fossa is plugged by the costal cartilage in an immovable primary cartilaginous joint.

ATYPICAL RIBS

First rib

The borders and pleural surface of this rib (Fig. 4.39) form part of the study of the thoracic cage, but its upper surface can be understood only when the anatomy of the root of the neck is known. The shaft is curved on the flat and, in conformity with the general convexity of the thoracic cage, the neck slopes down a little towards the head from the plane of the shaft. This can be seen, but if in doubt lay the rib on the table; head and anterior extremity both touch the surface. Laid upside down the neck slopes up to the head, which lies above the table. Thus can right and left sides be identified. Lift the rib from the table and study it in its *anatomical position*. The plane of the shaft is at 45° , and the tubercle is the most posterior and the highest part of the rib.

The **head** is small and carries a single facet for the synovial joint it makes with the upper part of the body of T1 vertebra. Capsule and synovial membrane are attached to the articular margin. A radiate ligament attached to the head reinforces the anterior part of the capsule. A slender **neck** slopes backwards and upwards to join the shaft. The anterior rami of nerves C8 (above) and T1 (below) lie in contact with the medial part of the neck. The sympathetic trunk (or cervicothoracic ganglion) lies in contact with the anterior border of the neck alongside the head. Lateral to it the supreme intercostal vein and then the superior intercostal artery lie in contact, and more lateral still the first thoracic nerve lies in front of the neck and inner border of the shaft (Fig. 4.5). The cervical dome of the pleura and the apex of the lung hold these vessels and nerves against the front of the neck of the rib.

The rib broadens at the junction of neck and shaft,

and here a prominent **tubercle** projects back to form the most posterior convexity of the rib. It is a fusion of tubercle and angle. Medially it has a cylindrical facet for a corresponding concavity on the first transverse process. The usual synovial joint exists here, with capsule and synovial membrane attached to the articular margins. The lateral prominent part of the tubercle receives the lateral costotransverse ligament and the costalis and longissimus parts of erector spinae.

The *under surface* of the **shaft**, crossed obliquely by the small first intercostal nerve and vessels is covered by adherent parietal pleura. The external and internal intercostal muscles are attached together to the outer rim of this surface. Some undulations in the shaft often produce broad grooves that can be mistaken for the subclavian grooves on the upper surface; if the surfaces are reversed the rib will be allotted to the opposite side. This mistake can be avoided by remembering the slope of the neck already studied. The outer border is blunt between the tubercle and subclavian groove. The anterior end of this blunt part is at the most lateral part of the convexity of the rib; this gives origin to part of the first digitation of serratus anterior. The posterior end of the blunt border is bare bone, and here scalenus posterior slides across the rib deep to serratus anterior. Forward of the subclavian groove the sharp external border is encroached on by the external intercostal muscle. The concave internal border of the shaft gives attachment to the suprapleural membrane in front of the subclavian groove (Fig. 4.5).

The *upper surface* of the **shaft**, sloping down at 45° , is at the root of the neck. It is grooved obliquely at its greatest lateral convexity (Fig. 4.5). Called the groove for the subclavian artery, it lodges the lower trunk of the brachial plexus (Fig. 4.39). The fibres in contact with the rib are all T1, and the C8 fibres lie above them, not yet intermingled. Note the direction of the groove; prolonged backwards it leads up to the neck of the rib, along the line of T1 nerve. The subclavian artery has its upward convexity lying more transversely. The artery does not lie in the groove, and it touches only the outer border of the rib. Between the groove and the tubercle the large quadrangular area of the upper surface gives attachment to scalenus medius. At the front of the groove the inner border is projected into a spur, the **scalene tubercle**. The ribbon-like tendon of scalenus anterior is attached to the tubercle and extends along a ridge across the upper surface halfway to the external border. In front of the subclavian groove, down the slope of the rib, is a second groove in which the subclavian vein lies in contact with the bone. The anterior end of the shaft

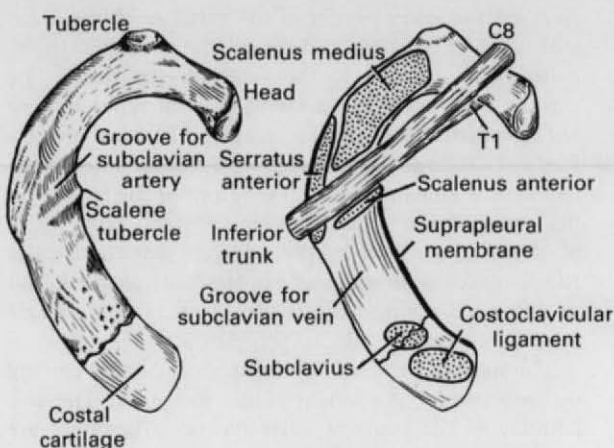


Fig. 4.39 Right first rib, from above, and attachments.

expands into a concavity for the first costal cartilage. From the upper surface of this junction subclavius arises from both bone and cartilage.

Second rib

This has a more slender shaft, and it makes a much larger curvature than the first (Fig. 4.40). It lies with its head slightly above the table. In the anatomical position its concave surface faces inwards as well as downwards. It possesses an angle about 1.5 cm ($\frac{1}{2}$ in) from its tubercle. The angle, not the tubercle, is the most posterior part of its curvature. The most lateral part of the curve shows a characteristic 'bump'—a rough tuberosity on the outer surface of the shaft, which in some bones resembles the callus of an old fracture. This is for the second and part of the first digitation of serratus anterior. Further back, about 3 cm (more than 1 in) lateral to the angle, the upper border is drawn up into a smaller 'bump' for the attachment of scalenus posterior. The other features of the second rib are as those of a typical rib; the costal groove is present but poorly developed.

Tenth rib

This is usually a typical rib, but is sometimes atypical in having a single facet for the head and no articular facet on the tubercle.

Eleventh rib

This has a single facet for the head and a short neck with no tubercle, but it retains a well-marked costal groove.

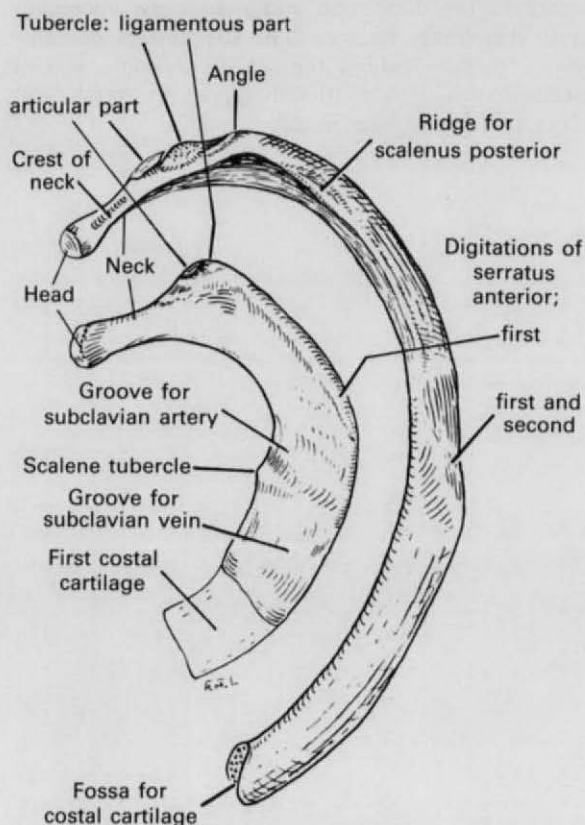


Fig. 4.40 Left first and second ribs, from above.

Twelfth rib

The gently curved twelfth rib varies in length. In conformity with the barrel-shaped contour of the thoracic cage the concavity of the shaft looks up a little instead of directly inwards like the others. The head has a single facet for T12 vertebra; the capsule and synovial membrane are attached to the articular margins. A short constriction forms a neck which passes imperceptibly into the shaft. There is *no tubercle, no angle and no costal groove*. A wide area of ridges on the convex surface of the shaft shows the attachment of erector spinae; lateral to this external oblique and latissimus dorsi arise and diverge from each other. The thin upper part of quadratus lumborum is attached to the medial part of the lower border; its markings may be difficult to identify. It does not extend as far out as erector spinae. The upper ends of the anterior and middle layers of the lumbar fascia are attached to the rib around the muscle. At the lateral limit of quadratus (and one may have to guess where this is)

the lateral arcuate ligament is attached. From here to the tip of the costal cartilage the diaphragm and transversus abdominis arise from the inner surface. From the diaphragm origin to the rib head the inner surface is clad by pleura which dips below the shaft in the costodiaphragmatic recess (p. 366). Lateral to quadratus the internal oblique is attached to the lower border. The external and internal intercostal muscles are attached along the upper border; there is commonly no posterior intercostal membrane in the eleventh intercostal space.

Lumbar ribs and cervical ribs are mentioned on page 537.

OSSIFICATION OF RIBS

Cartilage is laid down in mesoderm at the sixth week and a bony centre appears at the angle at the eighth week of fetal life. The head and tubercle remain cartilaginous and secondary centres appear at both places at about 15 years and fuse late (say 25 years).

OSSIFICATION OF THE STERNUM

In two longitudinal cartilaginous plates that fuse in the midline, a variable number of primary centres appear at about the fifth fetal month and later. There are one or two in the manubrium, and one or two in each of the four pieces (*sternebrae*) that will form the body of the sternum. The double centres coalesce, and fusion between sternebrae occurs between puberty and 25 years. Sternal foramina ('bullet holes') in the adult sternum are the result of incomplete fusion of double centres. The cartilaginous xiphoid process may ossify any time after the third year but often not until later life.

COSTAL CARTILAGES

These form primary cartilaginous joints at the extremities of all twelve ribs. The *first* is short and thick, and forms also a primary cartilaginous joint with the manubrium. It articulates with the clavicle and gives attachment to the sternoclavicular disc and joint capsule and, lateral to this, the costoclavicular ligament. The suprapleural membrane is attached to its upper border.

Below this the cartilages increase in length down to the seventh, which is the longest. From the fifth to the tenth they are bent from a downward slope in line with the rib to an upward slope towards the sternum (Fig. 4.3). Their medial ends form synovial joints (p. 243). On the eleventh and twelfth ribs there is a

pointed tip of cartilage. All cartilages, especially the first, tend to calcify and even ossify in patches after middle age. The costal cartilages give attachment to the anterior intercostal membranes and the internal intercostal muscles of their spaces, and the lower six give

origin to the diaphragm and transversus abdominis from their inner surfaces. The attachments of transversus thoracis behind the second to sixth, and of pectoralis major in front of the upper six costal cartilages have already been noted.

5. Abdomen

PART 1

ANTERIOR ABDOMINAL WALL

The skin and subcutaneous tissues of the anterior abdominal wall have been dealt with as part of the body wall (p. 241).

To facilitate the clinical description of pain, swellings, etc., the abdomen is divided into areas or regions that are defined by lines on the surface of the anterior abdominal wall. The simplest method is to divide it into four quadrants by vertical and transverse lines through the umbilicus, but usually nine regions are delineated by two vertical and two horizontal lines (Fig. 5.1). The vertical line on each side corresponds to the **midclavicular line**; when extended downwards it reaches the **midinguinal point**, which is on the inguinal ligament midway between the pubic symphysis and the anterior superior iliac spine. The lower transverse line is drawn

between the tubercles of the iliac crests (**intertubercular plane**) and the upper transverse line is in the **transpyloric plane** (p. 312), midway between the jugular notch and the top of the pubic symphysis (although some clinicians use the *subcostal plane* which is a little lower — level with the lowest part of the costal margin). Using these four lines, three central regions are defined from above downwards: *epigastric*, *umbilical* and *hypogastric* (or suprapubic). Similarly there are three lateral regions on each side: *hypochondrial*, *lumbar* and *iliac*.

ANTEROLATERAL ABDOMINAL MUSCLES

The three muscle layers of the body wall (p. 242) are separate in the flanks, where they are known as the external oblique, internal oblique and transversus abdominis muscles. The layers fuse together ventrally to form the rectus abdominis muscle. For recent comments on the traditional descriptions of muscular aponeuroses as given below, see the description of the rectus sheath on page 299.

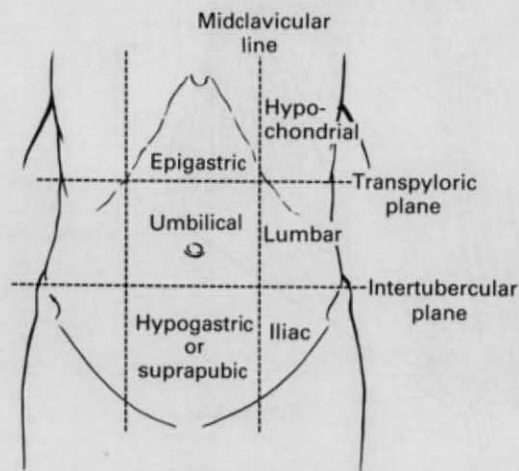


Fig. 5.1 Regions of the abdomen.

External oblique

The muscle arises by eight digitations, one from each of the lower eight ribs just lateral to their anterior extremities (Fig. 4.37, p. 288). The lower four slips interdigitate with the costal fibres of latissimus dorsi, the upper four with a corresponding number of the digitations of serratus anterior. From its fleshy origin the muscle fans out to a very wide insertion, much of which is aponeurotic. The muscle has three borders: a posterior muscular and upper and lower aponeurotic. The first two lie free.

Starting from behind at the twelfth rib the muscle may be traced to its insertion as fleshy fibres into the anterior half of the outer lip of the iliac crest. At the anterior superior iliac spine the muscular fibres give way to an aponeurosis; indeed no flesh is to be found

below a line joining this point to the umbilicus (Fig. 5.2). The limit of the fleshy fibres is visible in an athlete as a graceful curve. The aponeurotic fibres, directed obliquely downwards and forwards, are attached to the pubic tubercle and, interdigitating with each other above the pubic symphysis, cross the front of the rectus abdominis to the whole length of the linea alba up to the xiphisternum. The free upper border of this aponeurosis, extending from the fifth rib to the xiphisternum, runs horizontally. It is the only structure in the anterior sheath of the rectus muscle above the

costal margin. From it arise the lowermost fibres of pectoralis major. The lower border, lying between the anterior superior iliac spine and the pubic tubercle, forms the inguinal ligament.

The posterior border of the muscle is free, and forms the anterior boundary of the **lumbar triangle** (of Petit) that is floored in by the internal oblique and bounded behind by the anterior border of latissimus dorsi and below by the iliac crest. The triangle may be the site of a rare lumbar hernia (Fig. 2.5, p. 58).

The **inguinal ligament** (of Poupart) extends from

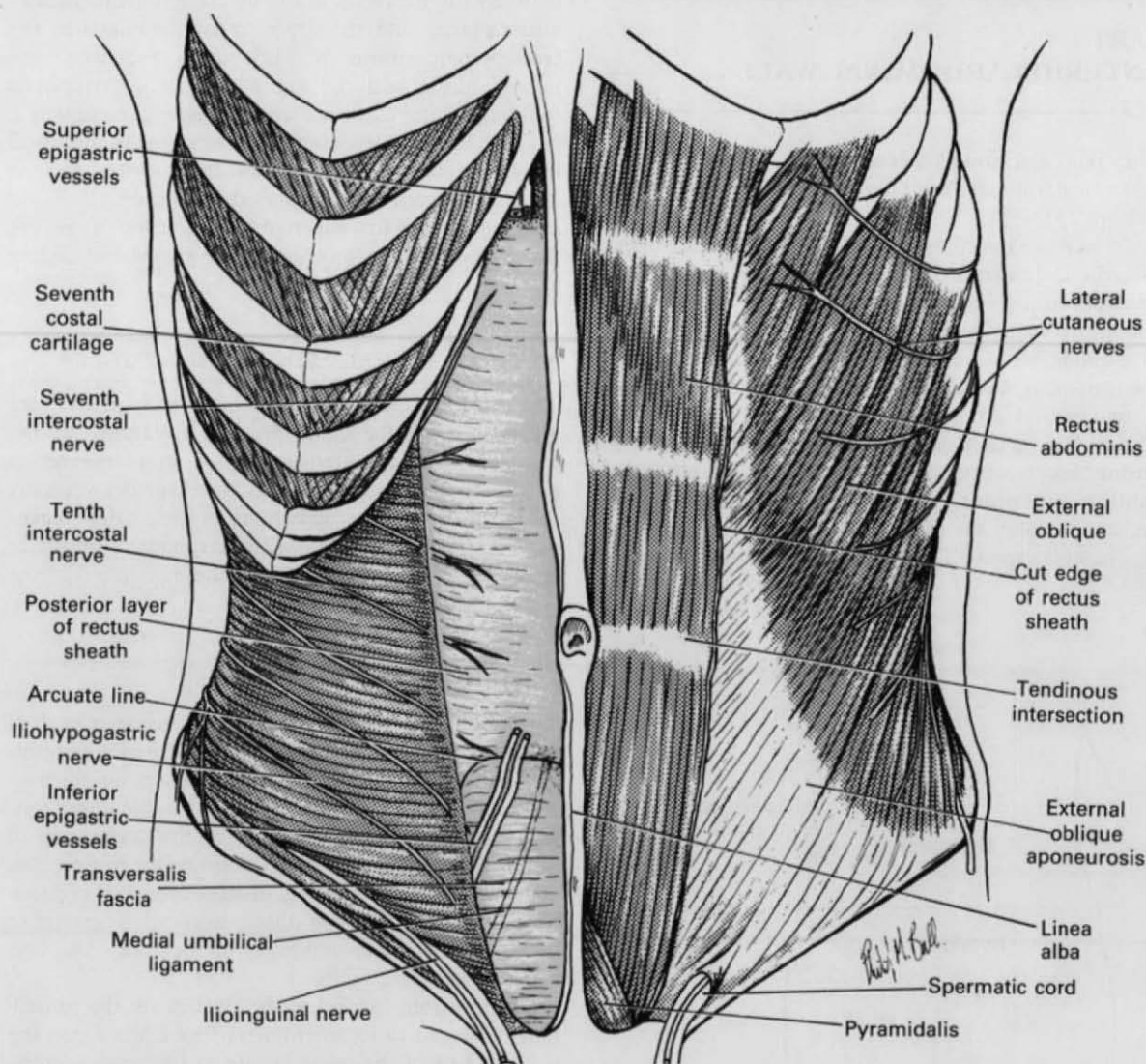


Fig. 5.2 Anterolateral abdominal muscles. The right rectus abdominis and pyramidalis have been removed to show the posterior wall of the rectus sheath, the arcuate line and the ends of the intercostal nerves.

the anterior superior iliac spine to the pubic tubercle. Its edge is rolled inwards to form a gutter; the lateral part of this gutter gives origin to part of the internal oblique and transversus abdominis muscles. To the inguinal ligament is attached the fascia lata of the thigh. When the thigh is extended the fascia lata pulls the inguinal ligament downwards into a gentle convexity.

Just above and lateral to the pubic tubercle is an oblique V-shaped gap, the superficial inguinal ring, in the aponeurosis (Fig. 5.3). This gap extends down to the pubic crest, medial to the tubercle; the aponeurosis is attached to the pubic crest only in its medial part, alongside the pubic symphysis. From the medial end of the inguinal ligament the **lacunar ligament** (of Gimbernat) extends *backwards* to the pectineal line. Its crescentic free edge is the medial margin of the femoral ring. From the pubic tubercle, fibres may be traced upwards and medially, behind the spermatic cord, to interdigitate in the linea alba with those of the opposite side. This is called the **reflected** part of the ligament (Fig. 5.3). Lastly, near the apex of the superficial inguinal ring are fibres running at right angles to those of the aponeurosis, the **intercrural fibres**, that blend and prevent the crura from separating (Figs 5.3 and 5.4).

Internal oblique

The fleshy fibres arise from the whole length of the lumbar fascia, from the intermediate area of the anterior two-thirds of the iliac crest and from the lateral *two-thirds* of the inguinal ligament (the rolled-in lower border of the external oblique aponeurosis). From the lumbar fascia the muscle fibres run upwards along the costal margin, to which they are attached, becoming aponeurotic at the tip of the ninth costal cartilage. Below the costal margin, the aponeurosis splits around

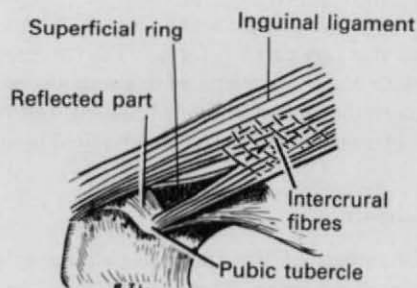


Fig. 5.3 Left superficial inguinal ring, after removal of the external spermatic fascia which is continuous with the margins of the ring.

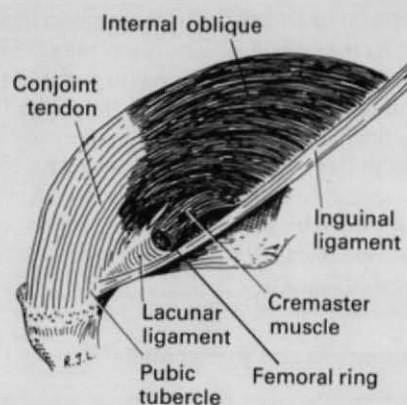


Fig. 5.4 Left conjoint tendon and lacunar ligament. The lowest fibres of the internal oblique arise from the inguinal ligament and arch medially to reach the conjoint tendon, forming as they do so the roof of the inguinal canal. They cover up the similar fibres of transversus abdominis, shown in Figure 5.5. Note that the nearly vertical conjoint tendon lies at right angles to the nearly horizontal lacunar ligament.

the rectus muscle, the two layers rejoining at the linea alba. The tendinous intersections of the rectus muscle are adherent to the anterior layer. At a point 2.5 cm (1 in) below the umbilicus the posterior layer ends in a curved free margin, concave downwards, the *arcuate line* or semicircular line (of Douglas). Below this point, the aponeurosis passes wholly in front of the rectus muscle, to the linea alba (Fig. 5.2) (but see p. 299).

The muscle fibres that arise from the inguinal ligament are continued into an aponeurosis that is attached to the crest of the pubic bone and, more laterally, to the pectineal line. The internal oblique has thus a free lower border, which arches over the spermatic cord — laterally the margin consists of muscle fibres in front of the cord; medially the margin consists of tendinous fibres behind the cord. The flat tendon, attached to the pectineal line, is fused with a similar arrangement of the transversus aponeurosis to form the conjoint tendon (Fig. 5.4).

Transversus abdominis

The muscle has a very long origin, in continuity from the whole costal margin, lumbar fascia, iliac crest and inguinal ligament. From the costal margin a fleshy slip arises *inside* each costal cartilage, interdigitating with the costal origin of the diaphragm; in continuity with the lowest costal fibres the muscle arises from the lumbar fascia lateral to the quadratus lumborum, then from the internal lip of the iliac crest in front of this (the anterior two-thirds of the crest), *from the fascia over*

iliacus and from the lateral half of the inguinal ligament, deep to the internal oblique. The muscle fibres become aponeurotic and pass behind the rectus to fuse with the internal oblique aponeurosis into the linea alba. Below the arcuate line (see under internal oblique muscle) the aponeurosis passes wholly in front of the rectus muscle, behind the aponeurosis of the internal oblique, which it accompanies laterally as the conjoint tendon on the pubic crest and along the pectineal line behind the spermatic cord (Fig. 5.5).

Rectus abdominis and pyramidalis

Rectus abdominis arises by two heads: a *medial* from in front of the pubic symphysis and a *lateral* from the upper border of the pubic crest by a relatively small tendon, but the belly rapidly thickens. The two muscles lie edge to edge in the lower part, but broaden out above, and are there separated from each other by the linea alba (Fig. 5.2). They are inserted into the thoracic cage. The bulk of the muscle passes in front of the costal cartilages and is attached to the fifth to seventh cartilages. This represents the external oblique layer (Fig. 5.6). Some of the fibres are inserted into the costal margin (i.e. the lower border of the seventh costal cartilage) representing the internal oblique layer. The transversus layer is represented by the xiphisternal fibres of the diaphragm (Fig. 5.6). Typically three *tendinous intersections* are found in the muscle, one at the umbilicus, one at the xiphisternum, and one between these two.

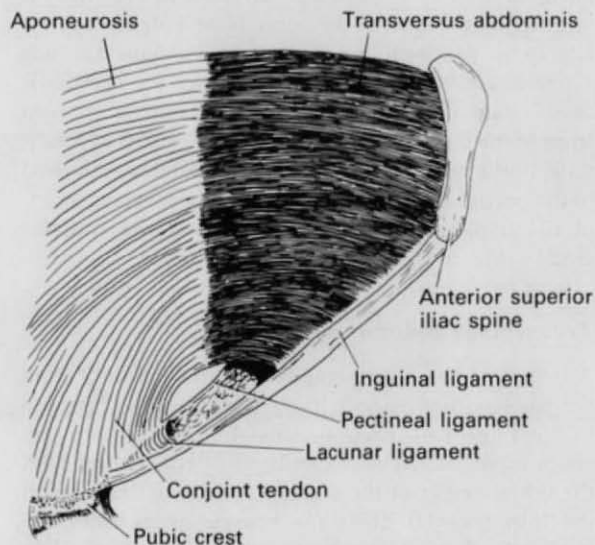


Fig. 5.5 Left transversus abdominis, showing the lowest fibres arching medially to join the conjoint tendon.

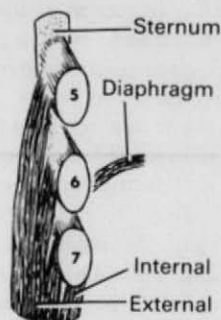


Fig. 5.6 Upper attachments of rectus abdominis, from the left, showing the three morphological layers of the muscle. 'External' indicates the external oblique layer passing over the fifth, sixth and seventh costal cartilages; 'internal' is the intermediate layer attached to the costal margin. The xiphisternal fibres of the diaphragm represent the innermost layer.

The muscle is formed by fusion of mesodermal somites as indicated by its regular segmental innervation but the tendinous intersections do not represent lines of fusion of myotomes; they are later developments and are sometimes found below the umbilicus. The tendinous intersections interchange fibres to blend inseparably with the anterior layer of the rectus sheath (see below). They occupy only the superficial part of the rectus and do not penetrate to the posterior surface of the muscle, which is thus not connected to the posterior layer of the sheath. The contracting rectus abdominis can be seen as bulgings between the tendinous intersections in an individual who is not too fat.

The small **pyramidalis** muscle arises from the pubic crest between rectus abdominis and its sheath. It converges with its fellow into the linea alba 4 cm or so ($1\frac{1}{2}$ in) above its origin.

Between the two recti all the aponeuroses fuse to form the **linea alba**, a strong midline fibrous structure which is firmly attached to the xiphoid process above and the pubic symphysis below (Fig. 5.2). Above the symphysis it is very narrow, for here the two recti are in contact with one another behind it. From just below the umbilicus to the xiphisternum it broadens out between the recti. Here the fibres form a tough felted membrane.

Rectus sheath

The aponeurosis of the internal oblique splits into anterior and posterior layers to enclose the rectus muscle (Fig. 5.7B). The external oblique aponeurosis fuses with the anterior layer to form the anterior layer of the sheath, and the transversus aponeurosis fuses with

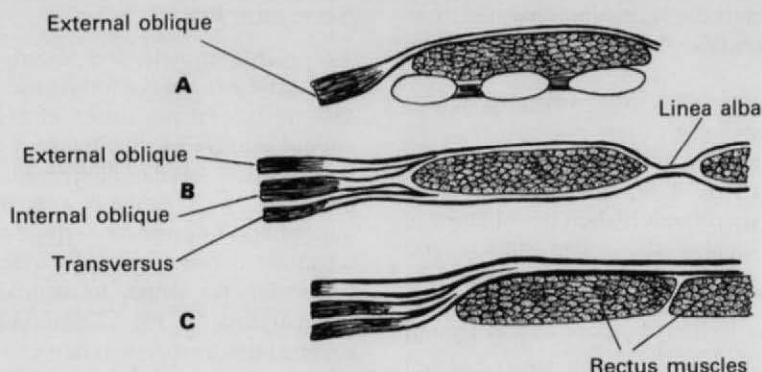


Fig. 5.7 Formation of the rectus sheath as seen in horizontal sections. **A** Above the costal margin; only the external oblique and its aponeurosis exist here. **B** Between the umbilicus and the costal margin; the aponeurosis of the internal oblique splits around the rectus, taking the external oblique aponeurosis to join the anterior layer and that of transversus to join the posterior layer. **C** Below the arcuate line; all three aponeuroses pass in front of the rectus muscle. See text for other possibilities.

the posterior layer to form the posterior layer of the sheath. A little below the umbilicus this arrangement ceases, and from this level downwards all three aponeuroses pass in front of the muscle (Fig. 5.7C). There is thus a free lower margin to the posterior layer; it is concave (though often ill-defined — see below) and properly named the *arcuate line* but sometimes known as the *semicircular line* (of Douglas). Below the umbilicus the aponeuroses of internal oblique and transversus fuse completely but that of the external oblique fuses only to the most medial part of the sheath. The posterior layer of the sheath is attached to the costal margin (seventh, eighth and ninth costal cartilages). At the front the rectus muscle passes over the costal margin to become attached to the fifth, sixth and seventh cartilages, as does the overlying external oblique aponeurosis, so that in this region the anterior layer of the sheath consists only of the external oblique aponeurosis (Fig. 5.7A).

The splitting of the internal oblique aponeurosis along the lateral border of the rectus muscle forms a relatively shallow (and bloodless) groove, the *semilunar line* (not to be confused with the *semicircular line*, above). It curves up from the pubic tubercle to the costal margin at the tip of the ninth costal cartilage in the transpyloric plane.

Recent studies indicate the need for some revision of traditional concepts of the rectus sheath and the aponeuroses that form it. It is suggested that all three aponeuroses are bilaminar, giving six layers in all, and that three form the anterior and three the posterior layers of the sheath, with considerable interdigitation

and decussation of fibres between adjacent layers, as far down as the umbilicus. There is no well-defined arcuate line but a gradual diminution of aponeurotic fibres with increasing thickness of the transversalis fascia. For many students and practitioners the old concepts may still be adequate, although new ideas about fibre patterns may be significant for movements of the thoracic walls and vertebral column. The lower thickened part of the transversalis fascia, between the iliac crest and pubis, is called the *iliopubic tract* by some authorities, who consider this and not the lacunar ligament to be the medial boundary of the femoral ring (p. 154).

Contents. Apart from the rectus and pyramidalis muscles, the sheath contains the ends of the lower six thoracic nerves and their accompanying posterior intercostal vessels, and the superior and inferior epigastric arteries.

The posterior **intercostal nerves** (T7–11, p. 246) pass from their intercostal spaces into the abdominal wall between the internal oblique and transversus muscles, and run round in this neurovascular plane to enter the sheath by piercing the posterior layer of the internal oblique aponeurosis. They then proceed behind the rectus muscle to about its midline (Fig. 5.2) where they pierce the muscle, supply it, and pass through the anterior layer of the sheath to become the **anterior cutaneous nerves**. In the sheath T7 runs upwards just below the costal margin, T8 transversely and the others obliquely downwards. Well before they reach the sheath the nerves have given off their lateral cutaneous branches, which pierce the internal and external

oblique in order to reach the skin. Note that it is these lateral cutaneous branches which supply the external oblique.

The lowest thoracic nerve, T12 or subcostal, is described on page 362.

The **superior epigastric artery**, a terminal branch of the internal thoracic (p. 248), enters the sheath by passing between the sternal and highest costal fibres of the diaphragm. It supplies the rectus muscle and anastomoses *within it* with the **inferior epigastric artery**. This vessel leaves the external iliac at the inguinal ligament (Fig. 5.10), passes upwards behind the conjoint tendon, slips over the semicircular fold and so enters the sheath. Veins accompany these arteries, draining to internal thoracic and external iliac veins respectively.

Blood supplies

Apart from the thoracic and epigastric vessels mentioned above, the anterolateral abdominal muscles also receive a blood supply from the lumbar and deep circumflex iliac arteries. The lumbar arteries are described on page 360; they end among the flat anterolateral muscles and do not reach the rectus sheath.

The **deep circumflex iliac artery** (p. 360) arises from the external iliac behind the inguinal ligament (Fig. 5.10), and runs laterally towards the anterior superior iliac spine in a canal of tissue where the transversalis and iliac fasciae meet. It continues along the inner lip of the iliac crest and pierces the transversus muscle to reach the neurovascular plane and anastomose with branches of the ilio-lumbar and superior gluteal arteries. At the anterior superior iliac spine it gives off an ascending branch which enters the neurovascular plane to anastomose with the inferior epigastric and lumbar arteries. This branch may be at risk in a gridiron incision (p. 311).

Lymph drainage

The superficial tissues of the anterolateral abdominal wall drain in quadrants: to the pectoral group of axillary nodes above the umbilicus on each side, and to superficial inguinal nodes below that level. The deeper parts of the wall drain into vessels in the extraperitoneal tissues. Above the umbilicus these pierce the diaphragm to reach mediastinal nodes, and below it they run to the external iliac and para-aortic nodes. There are, rather surprisingly, no lymph nodes in the abdominal wall to correspond to the intercostal nodes of the thoracic wall.

Nerve supplies

The rectus muscle and external oblique are both supplied by the lower intercostal and subcostal nerves (T7–T12; for their courses see below), and the internal oblique and transversus by those same nerves but with the addition of the iliohypogastric and ilioinguinal nerves (L1). It is the lowest fibres of the internal oblique and transversus — those that form the conjoint tendon — that receive the L1 innervation, which is thus responsible for helping to maintain the integrity of the inguinal canal (p. 304). The unimportant pyramidalis is supplied by the subcostal nerve (T12).

Actions of abdominal muscles

The muscles of the anterior abdominal wall play four main roles: (1) to move the trunk, (2) to depress the ribs (expiration), (3) to compress the abdomen (evacuation, expiration, heavy lifting) and (4) to support the viscera (intestines only). The abdominal wall, moving to and fro with breathing, conforms to the volume of the abdominal contents. Its *shape* is determined by the tonus of its own muscles. The subumbilical pull of healthy flank muscles keeps its lower part flat by holding back the lower recti.

Moving the trunk. It must be remembered that the muscles are attached to the thoracic cage and the bony pelvis; evidently their action is to approximate the two. They are the great *flexor muscles* of the vertebral column in its lumbar and lower thoracic parts. Rectus abdominis is the most powerful flexor, but all four oblique muscles, acting symmetrically, are important partners. The oblique muscles themselves (but not transversus) are *abductors* and *rotators* of the trunk. The external oblique of one side acts with the internal oblique of the other side to do this, an indispensable postural adjunct to almost all one-armed movements (e.g. tennis, boxing, etc.).

Depressing the ribs. The recti and obliques (but not transversus) approximate the ribs to the pelvic girdle. If erector spinae prevents thoracolumbar flexion this provides a powerful expiratory force (e.g. coughing, blowing the trumpet, speech-making). Added to this is the abdominal compression (aided by transversus) that elevates the diaphragm to increase the expiratory effort.

Compressing the abdomen. Flexion of the vertebral column is prevented by the erector spinae muscles. The oblique muscles compress the abdominal cavity; in this they are aided strongly by transversus abdominis, which has no flexing action on the spine. The recti play little part in compression. If the diaphragm is relaxed, it is forced up, and this is discussed with *expiration* on

page 251. At the same time levator ani helps to hold the pelvic effluents closed. The reverse occurs in *evacuation* of the pelvic effluents. Here the diaphragm contracts to resist upward displacement, but it is a far weaker muscle than the abdominal wall, and in forceful compression it is prevented from rising by 'holding the breath' (i.e. by closure of the glottis, and of perhaps the mouth and nasopharynx). This is discussed on page 502.

Supporting and protecting viscera. If the anterior abdominal wall is incised or removed, only the intestines spill out. At most the wall helps to support the intestines, suspended by their mesenteries; the upper abdominal viscera such as the liver, spleen and kidneys do not require the wall for this purpose, but reflex contraction in response to a blow helps to protect all viscera.

Tests. Rectus abdominis can be tested by lying flat on the back and raising the head (without using the arms). There are no specific tests for the other flat muscles, but the abdominal reflex and Beevor's sign have been referred to on page 29.

INGUINAL CANAL

The **inguinal canal** is an oblique intermuscular slit about 6 cm (over 2 in) long lying above the medial half of the inguinal ligament. It commences at the

deep inguinal ring, ends at the superficial inguinal ring, and transmits the spermatic cord and ilioinguinal nerve in the male and the round ligament of the uterus and ilioinguinal nerve in the female. Its anterior wall is formed by the external oblique aponeurosis (Fig. 5.8), assisted laterally by a portion of the internal oblique muscle (Fig. 5.9). Its floor is the inrolled lower edge of the inguinal ligament, reinforced medially by the lacunar ligament (Fig. 5.4) and fusing more laterally with the transversalis fascia. Its roof is formed by the lower edges of the internal oblique and transversus muscles, which arch over from in front of the cord laterally to behind the cord medially, where their conjoint aponeuroses, constituting the conjoint tendon, are inserted into the pubic crest and the pectineal line of the pubic bone. The posterior wall of the canal is formed by the strong conjoint tendon medially and the weak transversalis fascia laterally.

Anterior wall and superficial inguinal ring

The fibres of the external oblique aponeurosis run parallel with their lower border, the inguinal ligament. Above its medial end they diverge from each other to make a V-shaped opening, the **superficial inguinal ring** (Fig. 5.3). The *lateral crus* of this opening is

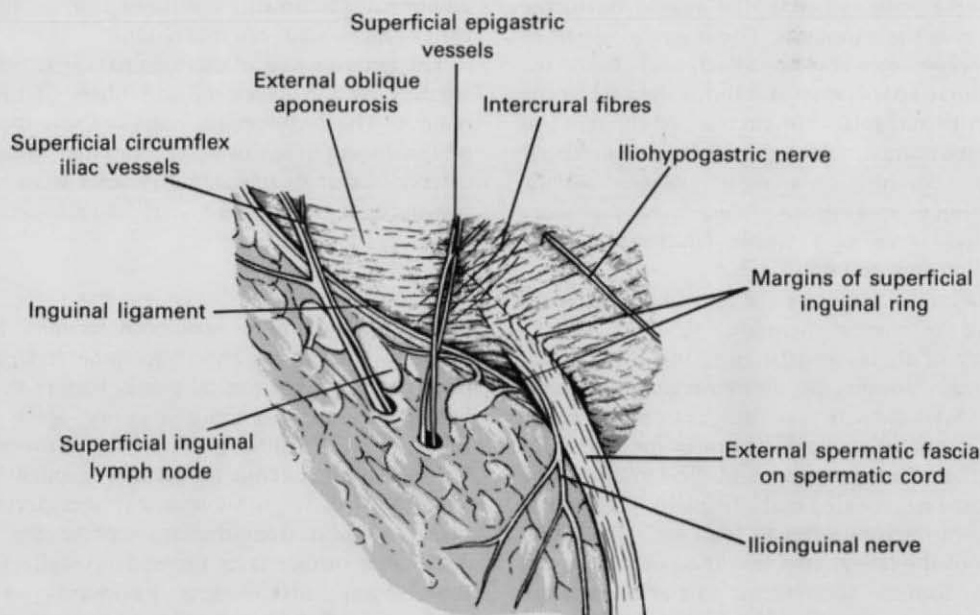


Fig. 5.8 Anterior wall of the right inguinal canal. The external oblique aponeurosis becomes the external spermatic fascia at the superficial inguinal ring.

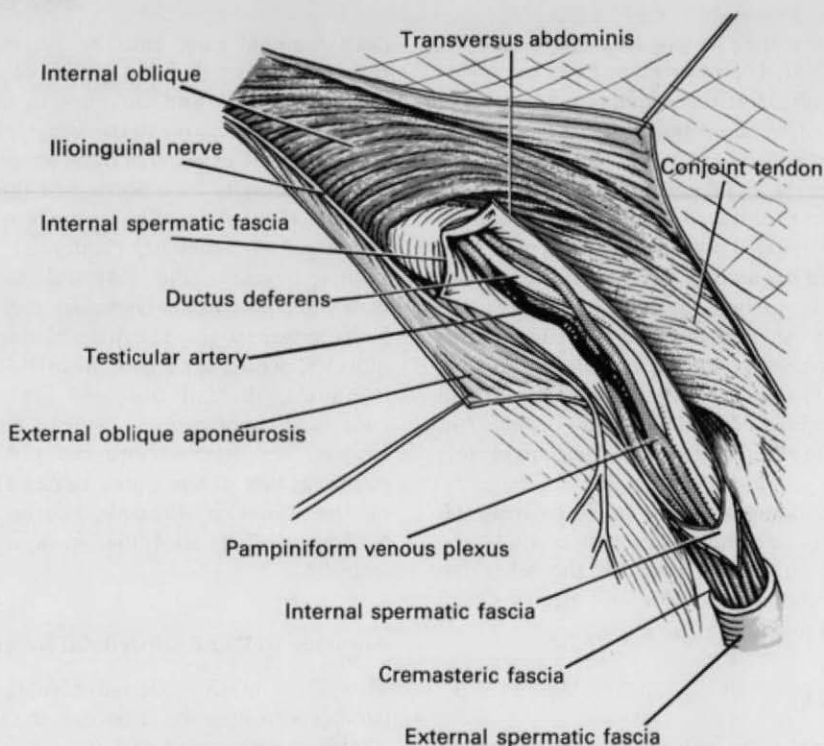


Fig. 5.9 Right inguinal canal after division of the external oblique aponeurosis and fasciae.

attached to the pubic tubercle, the *medial crus* to the pubic crest near the symphysis. The intervening part of the pubic crest receives no attachment from the external oblique aponeurosis and forms the base of the 'ring' which is triangular, not circular. At the point of junction of the crura are shining strands, the intercrural fibres (Fig. 5.3), running at right angles across the external oblique aponeurosis. They bind the crura together, and serve as a visible landmark for the superficial ring at operation (Fig. 5.8).

The crura can be demonstrated only by sharp dissection, cutting the external spermatic fascia free. Due to the obliquity of the superficial ring, the cord, which passes vertically downwards after emerging therefrom, *overlies the pubic tubercle*. For this reason the pubic tubercle is not readily palpable from in front, and for the satisfaction of the examiner and the comfort of the subject, should be palpated in the living by a finger that invaginates the scrotum *behind the cord*. From the attachment of the lateral crus (i.e. the pubic tubercle) some fibres, forming the *reflected part of the inguinal ligament*, pass upwards behind the cord and behind the medial crus to blend in the rectus sheath with those from the opposite side (p. 297). They constitute an

additional attachment, a *posterior crus*, of the aponeurosis of the *opposite* external oblique.

The anterior wall of the inguinal canal is reinforced laterally by the lowest muscle fibres of the internal oblique. The deep inguinal ring lies above the midpoint of the inguinal ligament; the internal oblique fibres extend medial to this, for they arise from the lateral two-thirds of the ligament (Figs 5.4 and 5.9).

Floor

Hold a hip bone in the position it occupies during life, with the anterior superior iliac spine and pubic symphysis in the same vertical plane. Picture the inguinal ligament, joining anterior superior spine to pubic tubercle. Note that the pectineal line of the pubic bone lies *superior* to it. Thus the lacunar ligament filling the angle between inguinal ligament and pectineal line, passes *upwards* from the ligament to the bone. Its abdominal surface faces forwards as well as upwards. Its femoral surface faces backwards as well as downwards. It lies in the floor of the inguinal canal (Fig. 5.4). Lateral to its attachment the incurved edge of the inguinal ligament forms a gutter which floors in

the inguinal canal. The transversalis fascia is fused with this part of the inguinal ligament.

Roof

This is formed by the arched lower borders of the internal oblique and transversus abdominis muscles (Figs 5.4 and 5.5). Each arises from the hollow of the inrolled lower edge of the inguinal ligament, but their precise attachments need to be appreciated separately. The internal oblique muscle arises by fleshy fibres from the lateral *two-thirds* of the inguinal ligament. The fibres arch medially and downwards, merging into a flat aponeurosis. The most lateral fibres, those arising from just below the anterior superior iliac spine, arch downwards to reach the pubic symphysis, in front of rectus abdominis. The remaining fibres (trace them medially along their origin at the inguinal ligament) arch concentrically within the former, passing in front of rectus abdominis along the pubic crest as far as the pubic tubercle and then extending laterally along the pectineal line as far as the crescentic edge of the lacunar ligament (Fig. 5.4). These lateral fibres, joining the

underlying transversus aponeurosis, constitute with them the **conjoint tendon**. The transversus abdominis lies more laterally at its origin, coming from only the lateral *half* of the inguinal ligament, by fleshy fibres deep to those of the internal oblique. They rapidly become tendinous and, fusing with the aponeurosis of the internal oblique, form the conjoint tendon which is attached along the pubic crest and extends laterally along the pectineal line (Fig. 5.10). Note that the conjoint tendon and the lacunar ligament, attached in common to the pectineal line, lie in planes at right angles to each other. The deep inguinal ring lies in the angle between the edge of transversus and the inguinal ligament. Since the internal oblique muscle arises a little more medially than this, it lies in front of the deep ring. The muscular arch of the roof, starting in the anterior wall of the canal, passes over the cord and, becoming tendinous, passes down behind the cord, in the posterior wall of the canal, to reach the pectineal line. Note the oblique course of the canal through the muscular layers of the abdominal wall; it is the obliquity of the canal which gives it strength.

The lowermost fibres of internal oblique and trans-

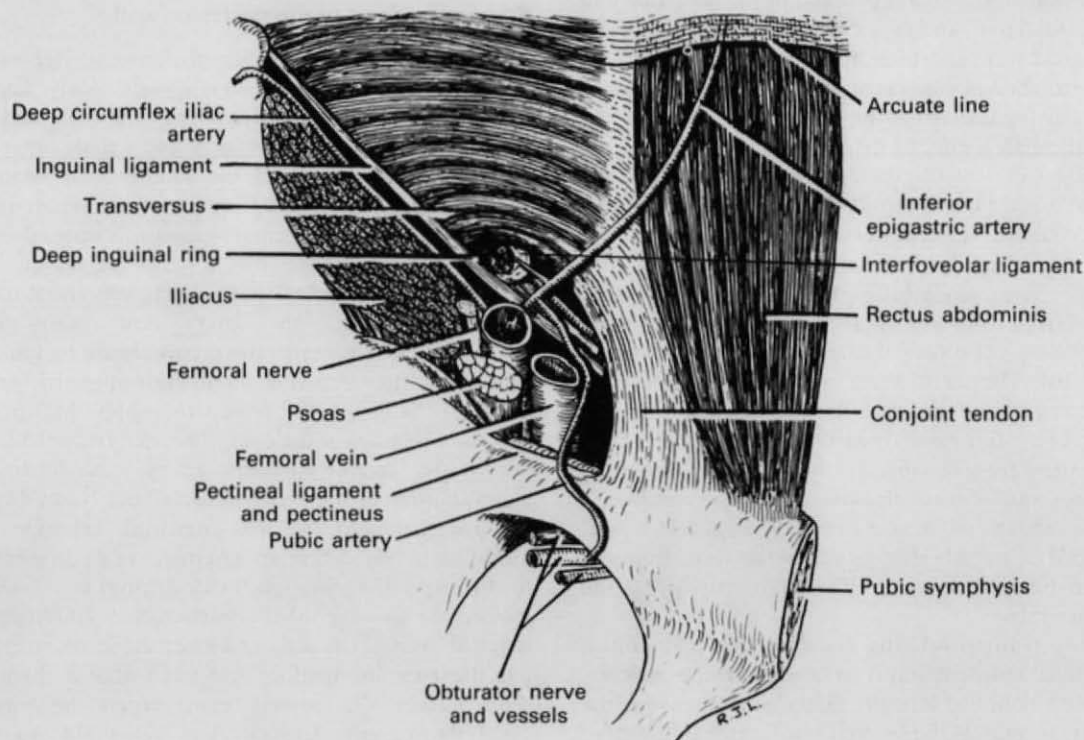


Fig. 5.10 Left inguinal region viewed from within the abdomen. The deep inguinal ring lies lateral to the inferior epigastric artery. The femoral ring lies medial to the external iliac (femoral) vein; the lacunar ligament which is at the medial border of the ring is here obscured by the conjoint tendon.

versus are supplied by the iliohypogastric and ilioinguinal nerves (L1). Their contraction tightens the conjoint tendon and lowers the roof of the canal, like pulling down a shutter. Thus division of the ilioinguinal nerve above this level (as in a split-muscle incision for appendectomy) leads to a direct inguinal hernia — the conjoint tendon bulges when intra-abdominal pressure rises. Note that damage to the ilioinguinal nerve as it lies in the *inguinal canal* does not paralyse these fibres; at this level the nerve is purely sensory, having already given off its motor fibres, and injury here will only cause some sensory loss over the anterior part of the scrotum (labium majus) and adjacent thigh.

Posterior wall and deep inguinal ring

Medially the posterior wall consists of the strong conjoint tendon, as already explained. Lateral to the conjoint tendon the wall is only thin, the gap between the arched roof (internal oblique and transversus muscles) and the floor (the inguinal ligament) being covered over by the weak areolar tissue of the transversalis fascia and peritoneum. The integrity of the inguinal canal depends upon the strength of the anterior wall in the lateral part and of the posterior wall in the medial part, and provided the abdominal muscles are of good tone and their aponeuroses unyielding no direct herniation of viscera can take place. The deep and superficial inguinal rings lie at opposite ends of the inguinal canal, 6 cm ($2\frac{1}{2}$ in) from each other, and the intervening part of the canal is pressed flat when the aponeuroses are under tension and the intra-abdominal pressure raised. The transversalis fascia in the posterior wall is strengthened, moreover, by the presence in front of it of certain tendinous, and sometimes muscular, fibres derived from the transversus abdominis muscle. These fibres constitute the **interfoveolar ligament** (Fig. 5.10). They arch down from the lower border of transversus around the vas to the inguinal ligament, and constitute the functional medial edge of the deep ring. They extend for a variable distance medially across the posterior wall of the inguinal canal and contain a variable amount of muscle fibres. The muscle is well developed in animals that withdraw the testis from the scrotum during their winter of sexual inactivity (e.g. the Canadian moose).

The **deep inguinal ring** lies above the midpoint of the inguinal ligament and is an opening in the transversalis fascia bounded laterally by the angle between the transversus muscle fibres and the inguinal ligament (Fig. 5.10). Its medial border is the transversalis fascia where this structure is projected along the canal, like a sleeve from the armhole of a coat, as the internal

spermatic fascia. The transversalis fascia is here thickened as the interfoveolar ligament.

Like the superficial ring, the deep inguinal ring (Fig. 5.10) is only a true gap when fascia, in this case the internal spermatic fascia, is cut away from its margins. Passing through the ring are the vas (ductus) deferens, and its artery (from the superior or inferior vesical), the testicular artery and the accompanying veins (usually double at this level), the obliterated remains of the processus vaginalis, autonomic nerves and lymphatics. Note that the ilioinguinal nerve, although classified as one of the contents of the inguinal canal (together with the spermatic cord or round ligament of the uterus), does not enter the canal through the deep ring but does so via the anterior wall of the canal by running between the external oblique aponeurosis and the internal oblique muscle, i.e. it slips into the canal from the side, not from the back. The nerve is not one of the constituents of the cord but runs in front of it. It leaves the canal through the superficial ring and supplies skin of the inguinal region, upper part of the thigh and anterior third of the scrotum (or labium majus).

Structures deep to the posterior wall

Crossing the posterior wall at the medial edge of the deep inguinal ring is the *inferior epigastric artery*. Lateral to the artery the ductus deferens in the male and the round ligament of the uterus in the female enter the canal by hooking around the interfoveolar ligament (Fig. 5.11). The artery is a branch of the external iliac just proximal to the inguinal ligament. It arises deep to the fascia transversalis, which it perforates obliquely as it slants upwards and medially. Lying superficial to the transversalis fascia the artery now passes over the arcuate line to enter the rectus sheath behind the muscle. At the deep ring the inferior epigastric artery gives off the *cremasteric branch* to supply that muscle and the coverings of the cord. The area bounded laterally by the inferior epigastric artery, medially by the lateral border of the rectus muscle, and below by the inguinal ligament is the **inguinal triangle** (of Hesselbach). By definition a hernial sac passing lateral to the artery (i.e. through the deep ring) is an *indirect hernia*, one passing medial to the artery (through the inguinal triangle) is a *direct hernia*; the latter stretches out the conjoint tendon over itself and is therefore seldom large. (A femoral hernia enters the femoral canal through the femoral ring, below the inguinal ligament and lateral to the lacunar ligament — p. 154.) The inferior epigastric artery also gives off a pubic branch to the periosteum of the superior pubic ramus.

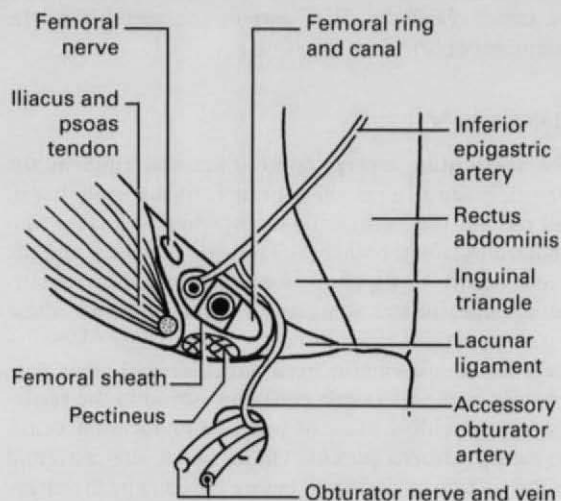


Fig. 5.11 Left femoral ring and adjacent structures, from behind. The accessory obturator artery is here lying at the medial margin of the femoral ring (lateral edge of the lacunar ligament) — the dangerous position if the ligament has to be incised to reduce a strangulated femoral hernia.

This anastomoses with the pubic branch of the obturator artery. If the obturator artery is absent, this anastomosis is opened up to form the *accessory or abnormal obturator artery*, which is present in about 50% of individuals (p. 396). The obliterated umbilical artery, known in the adult as the *medial umbilical ligament* (p. 313), passes obliquely across the posterior wall of the inguinal canal, medial to the inferior epigastric artery (Fig. 5.2).

SPERMATIC CORD

The ductus deferens and accompanying structures are conventionally considered as passing through the deep inguinal ring and along the inguinal canal to the superficial ring, picking up coverings from the layers of the abdominal wall as they do so (but as far as the passage of semen is concerned, the movement is of course in the opposite direction). All these structures make up the **spermatic cord**, whose components may be considered under two headings: the three coverings of the cord, and its six (groups of) constituents.

Of the three **coverings** (Fig. 5.12), the *internal spermatic fascia* is the investment derived from the transversalis fascia at the deep inguinal ring. As the cord passes through the ring into the inguinal canal, it picks up a second covering, the *cremasteric fascia* and *cremaster muscle*, from the internal oblique and transversus aponeuroses and muscles. The transversus muscle

fibres spiral down the cord and return behind it to become attached to the pubic tubercle. The internal oblique fibres, a larger contribution, also spiral around the cord and some return to the pubic tubercle but most return to the internal oblique itself. The third covering is from the crura of the superficial ring (external oblique aponeurosis), the *external spermatic fascia*. Strictly speaking the cord is only complete as it acquires this outer covering on emerging from the superficial ring.

The cremaster muscle can elevate the testis towards or even into the inguinal canal; although the fibres are skeletal the action is reflex rather than voluntary. This *cremasteric reflex* is particularly active in the infant and child and must be borne in mind when examining the scrotum in the young, to avoid an erroneous diagnosis of undescended testis.

The **constituents** of the cord consist of:

- (1) The ductus deferens, which usually lies in the lower and posterior part of the cord.
- (2) Arteries, the largest of which is the *testicular artery* (see below), with the *artery to the ductus* (from the superior or inferior vesical), and the *cremasteric artery* (from the inferior epigastric, Fig. 5.10) to the coverings.
- (3) Veins — the *pampiniform plexus* (see below).
- (4) Lymphatics, essentially those accompanying the veins from the testis to para-aortic nodes, but including some from the coverings which drain to external iliac nodes.
- (5) Nerves, in particular the *genital branch* of the *genitofemoral nerve* which runs among the coverings to supply the cremaster muscle, and is classified as part of the spermatic cord and not as a separate structure running through the inguinal canal. Other nerves are *sympathetic twigs* which accompany the arteries.
- (6) The *processus vaginalis*, the obliterated remains of the peritoneal connexion with the tunica vaginalis of the testis (and the constituent of the cord most commonly forgotten!). When patent it forms the sac of an indirect inguinal hernia (Fig. 5.13).

TESTIS

The **testis** (Fig. 5.12) is an oval organ possessing a thick covering of fibrous tissue, the *tunica albuginea*. To its *posterolateral surface* the *epididymis* is attached — an important point to remember when trying to distinguish between swellings of these two structures. The *vas* (ductus deferens) is the direct continuation of the epididymis (p. 308) and lies medial to it, the continuity being with its lower pole. The front and lateral surfaces of the testis lie free in a serous space formed by the

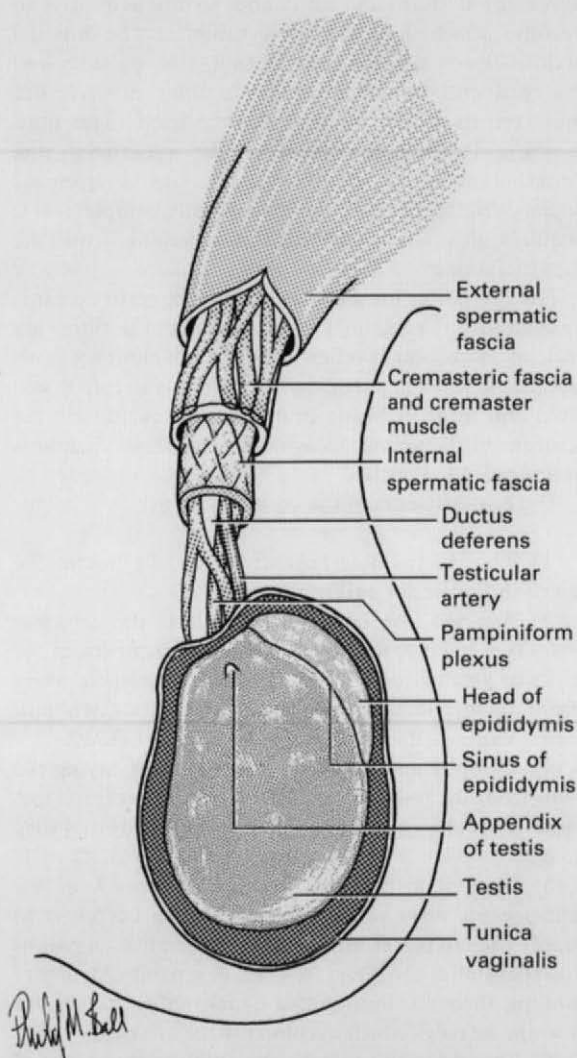


Fig. 5.12 Left testis and coverings of the spermatic cord.

overlying *tunica vaginalis*, a remnant of the fetal processus vaginalis. This serous membrane covers also the anterolateral part of the epididymis. In *hydrocele* of the testis the space of the tunica vaginalis becomes distended with fluid. A slit-like space, the *sinus of the epididymis*, which lies between testis and epididymis, is thus within the tunica vaginalis. Testis, epididymis and tunica vaginalis lie in the scrotum surrounded by thin membranes, adherent to each other, that are downward prolongations of the coverings of the spermatic cord. Right and left sides are separated by the median scrotal septum. The *appendix testis* is a sessile cyst 2 or 3 mm in diameter attached to the upper pole of the testis within

the tunica vaginalis. It is part of the remains of the paramesonephric duct (p. 309).

Blood supply

The **testicular artery**, from the aorta, runs in the spermatic cord, gives off a branch to the epididymis, and reaches the back of the testis, where it divides into medial and lateral branches. These do not penetrate the mediastinum testis, but sweep around horizontally within the tunica albuginea. Branches from these vessels penetrate the substance of the organ. Venules reach the mediastinum, from which several veins pass upwards in the spermatic cord and surround the testicular artery with a mass of intercommunicating veins, the **pampiniform plexus**. On its way to the testis and on the surface of the organ before entering it, the artery and its branches are intimately related to the venous plexus in order to provide a *countercurrent heat exchange*; for spermatogenesis the testis has to function at a temperature 2–4°C lower than rectal temperature. In the region of the epididymis there is an anastomosis between the testicular, cremasteric and ductal arteries. If the main artery is divided, the smaller vessels may not completely sustain the testis; atrophy may occur, though ischaemic necrosis is unlikely. In the inguinal canal the plexus may have separated out into about four veins which join to form two that leave the deep inguinal ring, perhaps becoming single on psoas major on the posterior abdominal wall (p. 361). The left vein invariably joins the left renal vein and the right is said to drain directly into the inferior vena cava, but it joins the right renal vein more commonly than most textbooks suggest. *Varicocele* (varicosities of the pampiniform and cremasteric veins) occurs much more frequently on the left side than the right, for reasons which are obscure. The only valves in the plexus and main veins are at the upper ends of the veins though the left vein is more often valveless than the right.

Lymph drainage

Within the testis, lymphatic capillaries lie between, not within, the seminiferous tubules. Lymphatics run back with the testicular artery to para-aortic nodes lying alongside the aorta at the level of origin of the testicular arteries (L2 vertebra), i.e. just above the umbilicus. The testicular lymph therefore does not drain to inguinal nodes, although the overlying scrotal skin does.

Nerve supply

The testis is supplied by sympathetic nerves. Most of

the connector cells lie in T10 segment of the cord. Passing in the greater or lesser splanchnic nerve to the coeliac ganglion the efferent fibres synapse there. Postganglionic grey fibres reach the testis along the testicular artery. Sensory fibres ('testicular sensation') share the same sympathetic pathway. They run up along the testicular artery and through the coeliac plexus and lesser splanchnic nerve and its white ramus to cell bodies in the posterior root ganglion of T10 spinal nerve. There is no parasympathetic supply to the testis.

Structure

The upper pole of the epididymis is attached high up on the posterolateral surface of the testis. Here there is a fibrous mass, the *mediastinum testis*, from which septa radiate to reach the tunica albuginea. The septa divide the testis into some 400 *lobules*, each of which contains two (sometimes three or four) highly convoluted *seminiferous tubules*. Each tubule is 60 cm (2 ft) long. The tubules lie rather loosely between the tunica albuginea and fibrous septa so that the cut surface of the organ bulges with herniating tubules. The seminiferous tubules open into the *rete testis*, which is a network of intercommunicating channels lying in the mediastinum testis. From the rete the *vasa efferentia*, 15 to 20 in number, enter the commencement of the canal of the epididymis, thus attaching the head of the epididymis to the testis.

Histological sections of the mature testis are easily recognized. The dense fibrous tissue of the tunica albuginea is thick, and fibrous septa divide the field into loculi. The seminiferous tubules, convoluted within the loculi, are cut in multiple sections. Each tubule shows several layers of cells. The outermost layer consists of *spermatogonia*, which divide to produce the cells of the next layer or two, the *primary spermatocytes* — the largest of the germ-cell series. These divide by *meiosis*, halving the chromosome number, to form *secondary spermatocytes* which are rarely identified because they have a very short life and divide almost immediately to form *spermatids*. These do not divide but undergo a metamorphosis into *spermatozoa*. The whole process of producing spermatozoa from spermatogonia is *spermatogenesis* and takes 64–70 days; the transformation of spermatids into spermatozoa is *spermiogenesis*. Different parts of a tubule show germ cells at different stages of development.

Among the developing germ cells are the supporting or *sustentacular cells* (of Sertoli). By their many branching processes which adhere to one

another (but not as a syncytium) they form an anastomosing network within which the germ cells are embedded, an arrangement that is only apparent on electron microscopy. The Sertoli cells secrete an androgen binding protein (ABP) which keeps a high concentration of testosterone in the germ cell environment.

Apart from spermatozoa, the testis makes a small contribution to semen (seminal fluid); most of it (60%) comes from the seminal vesicles (p. 385) and prostate (30%, p. 384).

Scattered among the cells of the connective tissue between the tubules (outside them) are the *interstitial cells* (of Leydig). Larger than fibroblasts, they constitute the endocrine portion of the testis, secreting testosterone, the male sex hormone necessary for spermatogenesis.

Descent of the testis

By the end of the fourth month of fetal life the primitive testis (derived from the gonadal ridge medial to the mesonephric ridge of the intermediate cell mass, p. 36) lies near the deep inguinal ring (Fig. 5.13), connected to that region of the anterior abdominal wall by a peritoneal fold. By the seventh month it is in the deep inguinal ring, and in the course of a few days during the next few weeks it progresses rapidly through the inguinal canal into the scrotum — this is 'descent of the testis' (the term does not mean movement down the posterior abdominal wall; growth of the trunk carries the kidney and suprarenal *upwards*, away from the testis). An elongated diverticulum of the peritoneal cavity, the *processus vaginalis* (Figs 5.13 and 5.14), has preceded the testis through the inguinal canal into the scrotum, and the testis moves down behind this. The processus normally becomes obliterated, except at the lower end where the testis bulges into it from behind and blends at its margins to form the tunica albuginea. The so-called visceral layer of the tunica vaginalis is testicular rather than coelomic in origin, in the same way that the surface epithelium of the ovary blends with the surrounding peritoneum (like the corneal epithelium with the conjunctiva).

Although the endocrine control of descent is reasonably well defined, the *mechanism of descent* is still not clear. It appears that the enlarging epididymis, attached to the testis before and during its descent, helps to push the testis down. The descent into the scrotum is preceded by the *gubernaculum* (a mesodermal condensation at the lower end of the gonad) which swells by the imbibition of water to

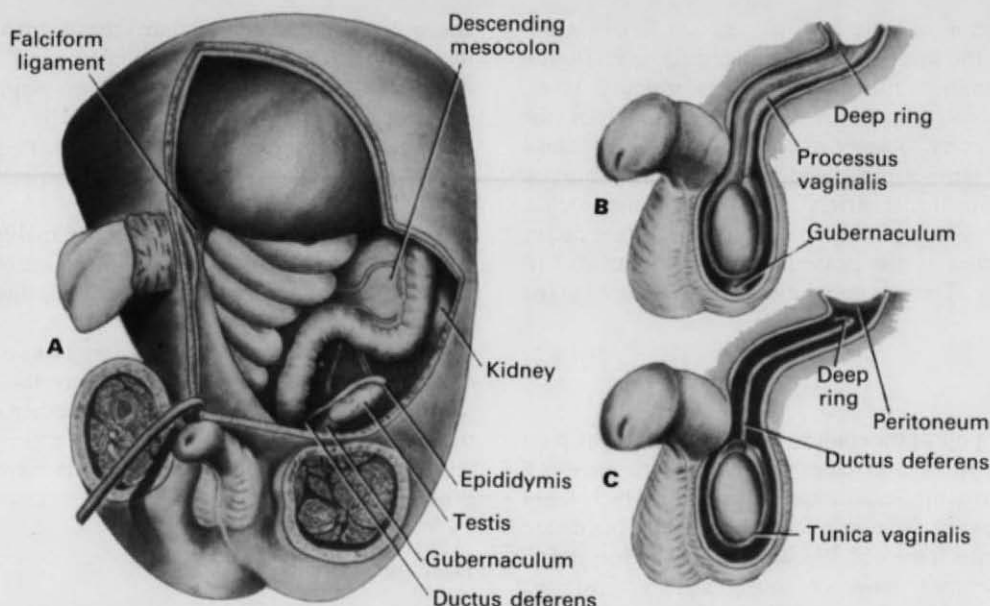


Fig. 5.13 Descent of the testis. **A** A 6-month fetus with the testis adjacent to the anterior abdominal wall near the deep inguinal ring. The ductus deferens descends from the lower pole (tail) of the epididymis. **B** In a neonatal specimen the gubernaculum is under the testis in the scrotum, and the ductus recurves from the tail of the epididymis behind the processus vaginalis of peritoneum. **C** With descent completed, the gubernaculum and processus vaginalis have disappeared. If the processus persists as a patent tube it provides a preformed hernial sac, as in the infantile type of congenital inguinal hernia.

enlarge a passage for descent. Contrary to earlier opinions, the gubernaculum does not become attached to the bottom of the scrotum and does not pull the testis down. However, it does appear to play an important role, possibly by preventing closure of the inguinal canal or directing the course of descent. Aberrant strands of gubernaculum may be associated with a testis in unusual sites (*ectopic testis*) in the inguinal or femoral regions or the perineum, but a causal relationship is not proven.

Failure to descend may result in *cryptorchid testis*, where it remains in the abdomen, or descent may be arrested anywhere from the deep inguinal ring downwards. Undescended testes are peculiarly liable to malignant disease; spermatogenesis is defective or absent but androgenic activity is not. They must be distinguished from *retracted testes*, where the cremaster muscle draws them back into the canal, especially in the young under the influence of cold examining hands! Failure of obliteration of the whole processus vaginalis gives rise to the congenital type of indirect inguinal hernia; localized persistence of part of the processus forms *hydrocele of the cord*. In the much commoner *hydrocele of the testis*, fluid fills the cavity of the tunica vaginalis.

EPIDIDYMIS AND DUCTUS DEFERENS

The **epididymis** is a firm structure, attached behind the testis, with the ductus deferens to its medial side. It consists of a single tube, 7 m (24 ft) long, highly coiled and packed together by fibrous tissue. The mass so resulting has a large *head* (upper pole, *globus major*) and a small *tail* (lower pole, *globus minor*) connected by the intervening *body*, which is applied in crescentic manner to the posterolateral part of the testis. A narrow slit between epididymis and testis is the *sinus of the epididymis*. The sinus, with the anterior half of the epididymis, lies within the tunica vaginalis. The head receives the vasa efferentia from the rete testis and is thus firmly attached to the testis. Elsewhere the epididymis has no functional connection with the testis, but it is firmly bound to it by fibrous tissue. It is an organ for the storage and maturation of spermatozoa.

From the tail the **ductus (vas) deferens**, a direct continuation of the canal of the epididymis, provided with a thick wall of smooth muscle, passes up medially. It enters the spermatic cord, passes through the inguinal canal, across the side wall of the pelvis just under the peritoneum, and crosses the pelvic cavity. It

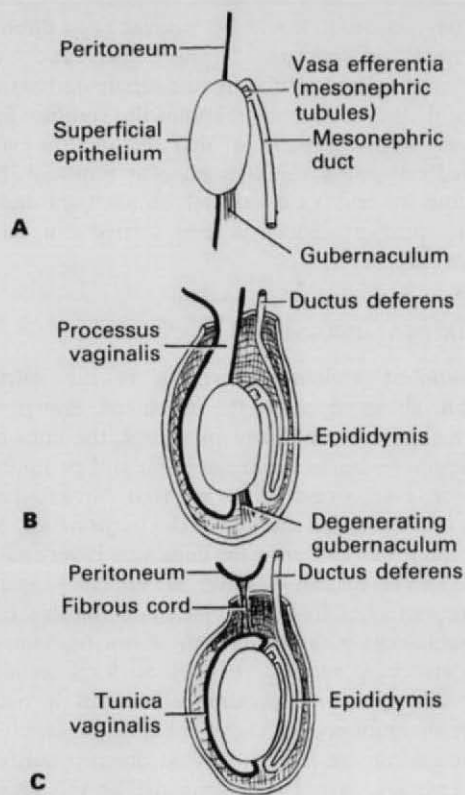


Fig. 5.14 Stages of testicular descent. **A** In the fetus, the testis projects through the peritoneum into the coelomic cavity. The ductus deferens (mesonephric duct) runs downwards. **B** In the neonate, the testis has reached the scrotum together with the tube-like prolongation of the peritoneal cavity, the processus vaginalis. **C** The end result, with the testis partly surrounded by the tunica vaginalis derived from the processus, and the rest of the processus reduced to a fibrous cord.

pierces the prostate and opens by the ejaculatory duct into the prostatic urethra (p. 385). Its pelvic course is described on page 385.

Blood supply

The epididymis is supplied by a branch of the testicular artery. This enters the upper pole and runs down to the lower pole. It anastomoses with the tiny artery to the ductus (p. 306).

Venous and lymphatic drainage are as for the testis (p. 306).

Nerve supply

The epididymis is supplied, like the testis, by sympa-

thetic fibres from the coeliac ganglion via the testicular artery.

Structure

Histological sections of the epididymis are easily recognized. One single coiled tube is cut many times; circles, ovals or comma-shaped outlines of a constant diameter are seen. The wall is of thin fibrous tissue, and the lining is of tall columnar epithelium with stereocilia, which are not true cilia but long, non-motile microvilli. Fibrous tissue binds the coils together.

The ductus deferens, or vas, is characteristic. Its wall is very thick in contrast to the narrow lumen. The thick wall is of visceral muscle, typically arranged in three layers—middle circular and inner and outer longitudinal—but there is often interweaving of fibres. The lining mucous membrane is a *thin* layer of *dense* fibrous tissue, surfaced with tall columnar epithelium with stereocilia like that of its parent epididymis.

Development

The whole length of the single tube constituting the epididymis and ductus is a persistent and much elongated part of the **mesonephric** (Wolffian) **duct** of the embryo. This duct receives the efferent tubules of the mesonephros (Fig. 5.15 and p. 370). When the mesonephros is replaced by the metanephros and disappears, some of its tubules persist and attach to the developing testis, forming the vasa efferentia and draining the products of the testis into the commencement of the mesonephric duct. Some mesonephric tubules persist without serving any function of drainage, since they are blind at one or both ends. Thus, above and below the epididymis blind tubules, the *vasa aberrantia*, open into its canal. Their bulbous blind ends may form small swellings; an upper one is relatively constant, the *appendix of the epididymis*. Above the epididymis, at the lower extremity of the spermatic cord, a mass of tubules, blind at each end, persists as the *paradidymis* (organ of Giralès). A cyst formed from an aberrant vessel will contain spermatozoa and thus be opalescent. A cyst formed from a tubule of the paradidymis cannot contain spermatozoa, and its fluid is thus crystal clear.

The **paramesonephric** (Mullerian) **duct**, developing into the uterine tube and uterus (p. 390), disappears in the male except at its two ends. The upper end persists as the *appendix testis*, the conjoined lower ends of the two ducts persist as the *prostatic utricle* (*utricle masculinus*) (p. 385).

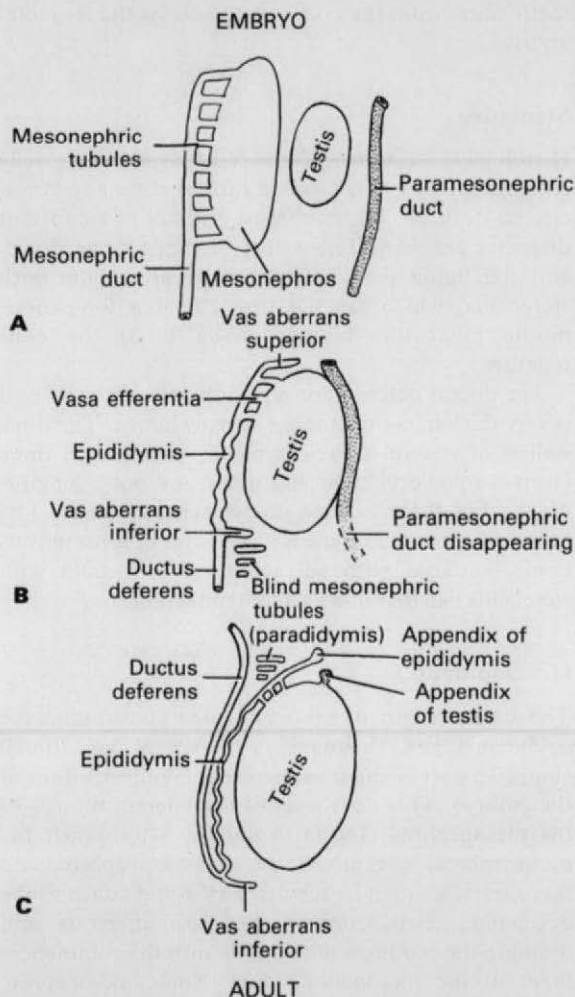


Fig. 5.15 Development of the epididymis and vasa efferentia. **A** In the earliest stage, the mesonephros drains urine into the mesonephric duct, and the gonad develops between the mesonephros and the paramesonephric duct. **B** At a later stage the mesonephros disappears but its duct persists. Some mesonephric tubules remain as vasa efferentia, to carry spermatozoa from the testis to the part of the mesonephric duct that becomes the epididymis. **C** The adult relationships after descent of the testis. The ductus deferens, formerly running downwards, now runs upwards from the epididymis, carrying blind mesonephric tubules (paradidymis) from the lower to the upper pole of the testis. The appendix of the testis is the remains of the paramesonephric duct.

Vasectomy

The 'vas' is now renamed the 'ductus deferens'. But sterilization of the male by division and ligation of the tube is still popularly known as 'vasectomy' (more

accurately, vasotomy), and has not yet been dubbed a 'deferential dochotomy'. The spermatic cord containing the firm tubular ductus is palpated between the thumb and fingers at the top of the scrotum and a transverse incision made so that the ductus can be dissected out and a small length of it removed. Each remaining cut end is turned back on itself and ligated, and the same procedure is then carried out on the opposite side.

ABDOMINAL INCISIONS

The simplest abdominal incision is the **midline incision**, above or below the umbilicus, and passing through skin and subcutaneous tissues, the linea alba, transversalis fascia, extraperitoneal fat and peritoneum. No major vessels or nerves are involved, but a few small vessels may cross the midline of the peritoneum. Note that in the lower abdomen the linea alba is very narrow and the two rectus muscles may lie very close together; poor suture technique leads to incisional hernias. In the suprapubic region the bladder must not be damaged. For laparoscopic surgery, the incision for insertion of the needle to induce pneumoperitoneum is usually made in the midline, just above or below the umbilicus, and the instrument is first directed down towards the pelvic cavity to avoid damaging the aorta. Separate incisions are made for other instruments, often lateral to the rectus sheath but not too low, to avoid the inferior epigastric vessels; transillumination from behind helps to avoid them. Other openings can be made above the umbilicus to the left of the midline (to avoid the falciform ligament which lies increasingly towards the right), or in the midclavicular or midaxillary lines nearly level with the umbilicus. Sites below the umbilicus or at the lateral border of the rectus sheath are also used for the insertion of a trocar and cannula for drainage of peritoneal fluid (paracentesis) or for a peritoneal dialysis catheter.

In a **paramedian incision**, the anterior wall of the rectus sheath is incised vertically 3 cm from the midline and the rectus muscle either retracted laterally or split so that the posterior wall of the sheath can be incised. The tendinous intersections in the rectus muscle at and above the umbilicus may have to be dissected off the anterior wall of the sheath; they may contain vessels. Above the umbilicus on the right the falciform ligament may have to be divided. If the rectus is split instead of being retracted, the split should not be more than 1 cm from the medial border in order to avoid the intercostal nerves which pierce the muscle near its midline. The small part of the muscle medial to the split will be denervated and devascularized but this does not cause

problems. The lack of a posterior wall of the sheath below a point midway between the umbilicus and pubic symphysis implies that sound healing depends on proper closure of the sheath's anterior wall.

An incision similar to the paramedian but near the lateral border of the rectus sheath (*pararectal* incision) was formerly popular, but has now been abandoned because of damage to the nerves entering the sheath laterally.

The **right subcostal (Kocher's) incision** is made 3 cm parallel to and below the right costal margin, from the midline to beyond the lateral border of the rectus sheath. The anterior layer of the sheath (with the external oblique) and the rectus muscle are divided in the line of the skin incision, with ligation of the superior epigastric vessels and/or their branches. The posterior layer of the sheath is then incised, continuing laterally into the internal oblique and transversus and through to the peritoneum. The seventh intercostal nerve follows the costal margin upwards and is usually above the incision line, although the eighth or ninth nerve may have to be cut, with little effect on the rectus muscle. They should be preserved if possible but cutting more than two (paralysing more of the rectus) should be avoided.

The double Kocher or **rooftop incision**, combining subcostal incisions on both sides, gives a very wide exposure of the upper abdomen.

The **gridiron (McBurney's) incision** is a right lower oblique muscle-splitting incision, long used for appendectomy. The skin incision is through the junction of the outer and middle thirds of a line drawn from the anterior superior iliac spine to the umbilicus and can be made either parallel to the iliac crest or transversely. The external oblique muscle and its aponeurosis are divided in the line of the muscle fibres and then the internal oblique and transversus are split transversely (in the line of their own fibres). The two muscles are close and may appear as one; the transversus becomes aponeurotic at this level and adheres to the transversalis fascia. The peritoneum can then be incised. The iliohypogastric and ilioinguinal nerves may be seen between the internal oblique and transversus and must not be damaged, to avoid weakening the protective effect that the muscles exert upon the inguinal canal (p. 304). Extending the incision laterally may cut the deep circumflex iliac artery's ascending branch (p. 300), which runs upwards above the anterior superior iliac spine between the internal oblique and transversus.

For cosmetic reasons the gridiron incision is often replaced by a more **transverse muscle-splitting incision**, starting above and medial to the anterior

superior iliac spine and extending nearly to the lateral border of the rectus sheath.

Transverse muscle-cutting incisions can be made above or below the umbilicus, cutting one or both rectus sheaths and muscles and extending laterally into the obliques and transversus, or just cutting the more lateral muscles. Intercostal nerves run obliquely through the lower abdominal wall, but more than one is not likely to be cut by these transverse incisions.

The **oblique muscle-cutting incision** (Rutherford Morison's) is similar to the gridiron but after incising the external oblique in the line of its fibres the internal oblique and transversus are cut in the same line (not in the line of their own fibres).

The lower abdominal **transverse incision** (Pfannenstiel's) is commonly used for approach to the pelvic organs. A slightly up-curving skin incision is made 3 cm above the pubic symphysis as far as the lateral borders of the rectus sheaths. The anterior layers of the rectus sheaths are divided in the line of the skin incision and flaps dissected off the muscles both upwards and downwards, including midline tissue and with the pyramidalis muscles included in the lower flap. The rectus muscles which at this level lie close together are separated, and linea alba is then incised vertically to expose extraperitoneal tissue, followed by incision of the peritoneum, with care to avoid the bladder. Transverse division of the rectus muscles gives wider exposure, and the incisions can be extended laterally into the flat muscles.

A **lumbar incision** is used for extraperitoneal approach to the kidney and upper ureter. The incision extends below the twelfth rib from the lateral border of erector spinae towards the anterior superior iliac spine. Latissimus dorsi and external oblique are incised and their cut edges retracted so that the internal oblique and transversus merging with the lumbar fascia can also be incised. The subcostal nerve deep to internal oblique should be preserved but the vessels can be ligated. The transversalis fascia and extraperitoneal fat in the posterior part of the incision are separated to expose the renal fascia. The peritoneal cavity is not entered. Proper identification of the twelfth rib (especially when short) is essential, to avoid entering the pleural cavity (p. 281).

PART 2 ABDOMINAL CAVITY

The abdominal cavity is much more extensive than the

impression gained from examination of the anterior abdominal wall. Much of it lies under cover of the lower ribs, for the domes of the diaphragm arch high above the costal margin. Hidden by the lower ribs are the whole of the liver and spleen, much of the stomach, and the upper poles of the kidneys and both suprarenals. The volume of the thoracic cavity is, correspondingly, much less than examination of the bony thorax would suggest. Furthermore, an appreciable amount of the abdominal cavity projects backwards into the pelvis, just in front of the buttocks. A perforating wound of the buttock can easily involve the pelvic cavity. The pelvic cavity accommodates not only its own pelvic organs (rectum, uterus, bladder, etc.), but also a goodly volume of intestine (sigmoid colon and ileum).

GENERAL TOPOGRAPHY OF THE ABDOMEN

The alimentary canal and its two chief derivatives the liver and pancreas (and also the spleen) are developed in fetal mesenteries which later alter their disposition as a result of fusion of adjacent leaves of peritoneum. The liver and spleen remain invested in peritoneum, but the pancreas becomes retroperitoneal.

The alimentary canal is invested unevenly. Parts of it are free to swing on peritoneal folds ('mesenteries'); other parts become plastered down to the posterior abdominal wall. The stomach is fixed at its two ends, but elsewhere swings free on 'mesenteries'. The duodenum is plastered down to the posterior abdominal wall, while the whole length of small intestine swings free on its own mesentery. The ascending and descending colon are both adherent to the posterior abdominal wall, but between the colic flexures the transverse colon is mobile on its own mesentery, the transverse mesocolon. The sigmoid (pelvic) colon swings free on a mesentery while, lastly, the rectum is plastered by peritoneum to the hollow of the sacrum.

The suprarenals, kidneys and ureters lie behind the peritoneum and possess no serous coat. The aorta and inferior vena cava also lie behind the peritoneum. The intestinal vessels run through the mesenteries to reach the gut.

The division of the abdominal cavity into regions by vertical and horizontal planes (Fig. 5.1) is useful but gives no aid in understanding abdominal topography. By far the most useful plane is the transpyloric plane, and if the structures lying at this level are appreciated the topography of the rest of the abdominal organs becomes clear.

The **transpyloric plane** bisects the body between the jugular notch and the pubic symphysis. But the plane need not be defined with geometrical accuracy

and it is sufficient to mark it as passing through a point midway between the xiphisternum and the umbilicus, or about a handsbreadth below the xiphisternal joint (Fig. 5.1). It cuts each costal margin at the tip of the ninth costal cartilage, which is at the lateral border of the rectus abdominis (semilunar line); beneath this point on the right side lies the fundus of the gall bladder, on the left is the body of the stomach. The plane passes through the lower border of the first lumbar vertebra, where the spinal cord ends at the conus medullaris.

As its name implies, the plane passes through the pylorus. It must be noted that the pylorus is free on a mesentery, and therefore mobile. In the erect posture it hangs down over the front of the head of the pancreas, so the plane passes along the head, neck and body of that gland, just above the attachment of the transverse mesocolon. The supracolic compartment (liver, spleen, fundus of stomach) lies above the plane, the infracolic compartment (small intestine, colon) below it. The superior mesenteric artery leaves the aorta at this level, and the splenic vein runs transversely behind the pancreas in the plane. The hilum of each kidney lies at the plane, the right just below and the left just above it, level with the tips of the ninth costal cartilages.

PART 3 PERITONEUM

The **peritoneum** is a serous membrane which lines the abdominal cavity; it covers the anterior and posterior walls, the under surface of the diaphragm and the pelvic cavity. All this is the **parietal peritoneum**. In places it leaves the posterior abdominal wall or diaphragm to form a partial or complete investment for viscera; this is the **visceral peritoneum**, which forms the serous covering for many viscera.

Peritoneum consists of a single layer of flattened cells, *mesothelium*, overlying areolar tissue which varies in both thickness and density in different places. Over expansile parts this areolar tissue is loose and cellular (e.g. transversalis fascia on the lower anterior abdominal wall) while over non-expansile parts it is often very thick (e.g. iliac fascia, psoas fascia, parietal pelvic fascia); but loose or dense, thin or thick, these variously named fasciae are part of the one continuous extraperitoneal connective tissue lying between the parietal peritoneum and the walls of the abdominal and pelvic cavities. On the posterior abdominal wall the dense psoas and iliac fasciae and the anterior layer of the

lumbar fascia serve as firm bases upon which the extraperitoneal tissue can gain attachment. The posterior surfaces of retroperitoneal structures (pancreas, duodenum, ascending and descending colon) also gain a firm attachment to these fasciae. Thus peritoneum and viscera have a firm anchorage undisturbed by the movements of contraction of the underlying muscles.

Various folds or reflexions of peritoneum connect viscera to the abdominal walls or to one another. Some of these are properly called *folds*, but others may be called a mesentery, omentum or ligament. The double fold supporting most of the small intestine is the *mesentery*; the mesenteries supporting the transverse colon, sigmoid colon and appendix are the *transverse mesocolon*, *sigmoid mesocolon* and *mesoappendix*. The *lesser omentum* connects the stomach to the liver, and the *greater omentum* hangs down from the lower border of the stomach. The various *ligaments* associated with the liver, stomach and spleen are simply peritoneal folds and bear no relation in structure or strength to the ligaments of muscles and joints; the name as applied to peritoneum is an unfortunate one. A few of these peritoneal structures are easy to see on opening the abdomen through the anterior abdominal wall (e.g. the greater omentum and the mesentery), but others can only be properly appreciated when viscera are displaced or removed.

Peritoneal folds of the anterior abdominal wall

On the posterior surface of the anterior abdominal wall the peritoneum is raised into *six folds*, one above and five below the umbilicus. Passing upwards from the umbilicus behind the linea alba towards the xiphisternum is the **falciform ligament**. It contains in its posterior and slightly crescentic free margin the *ligamentum teres* (the obliterated remains of the left umbilical vein, p. 46), which enters the fissure of that name on the visceral surface of the liver. Having 'delivered' the ligamentum to the liver, this double-layered fold continues up and to the right of the midline, between the diaphragm and the anterior and superior surfaces of the liver, where the two layers separate (Fig. 5.35A and as described on p. 342). For the present, note that although the lower part of the ligament is attached to the midline of the abdominal wall, the posterior free margin deviates to the *right* of the midline while containing the remains of the *left* umbilical vein.

Below the umbilicus there is a central fold with a pair on either side. Centrally is the *median umbilical fold*, containing the *median umbilical ligament* (the obliterated remains of the urachus). On each side, and also running

as far as the umbilicus, is the *medial umbilical fold*, containing the *medial umbilical ligament* (the obliterated remains of the umbilical artery). Farther laterally is the *lateral umbilical fold*, containing the *inferior epigastric vessels*, which enter the rectus sheath by passing beneath the arcuate line; although called umbilical folds, this lateral pair do not reach as far as the umbilicus.

Peritoneal cavity: greater and lesser sacs

The serous-coated organs fill the abdominal cavity so that visceral surfaces are in contact with one another or with the parietal peritoneum. The space between them is only potential, not actual, and it contains only a few millilitres of tissue fluid which lubricates adjacent surfaces so they can glide over one another. This is the **general peritoneal cavity**, body cavity or coelom, and is opened up when incisions that include parietal peritoneum are made through the abdominal wall. Another name for it is the **greater sac**.

The **lesser sac**, properly called the *omental bursa*, is a diverticulum of the peritoneal cavity behind the stomach. It exists because of the way the liver, stomach and spleen change their positions and shapes during development, and its purpose is to provide a slippery surface for the necessary mobility of the posterior surface of the stomach (Fig. 5.16). It opens into the greater sac through a slit-like aperture in front of the inferior vena cava, the *epiploic foramen* (Fig. 5.38, and see below).

Theoretically the cavity of the lesser sac should extend down between the layers of the greater omentum (Fig. 5.16), but because of the fusion of layers it rarely extends much below the stomach. The lesser omentum and stomach form the anterior wall of the sac (Fig. 5.16). To the left the sac extends to the hilum of the spleen (Fig. 5.47), where the peritoneum forms the lienorenal and gastrosplenic ligaments (described below), while at its right edge is the epiploic foramen, also described below with the lesser omentum. The sloping roof of the sac is the peritoneum covering the caudate lobe of the liver (Figs 5.16 and 5.35B), and this is continuous with the peritoneum of the posterior wall which overlies part of the diaphragm, pancreas, left kidney and suprarenal gland (Fig. 5.17). The lowest part of the posterior wall is the transverse mesocolon, attached to the lowest part of the pancreas (Fig. 5.17). Many of these posterior wall features can only be properly understood when this region of the posterior abdominal wall and its associated structures have been considered, but some further details should be noted now.

A finger introduced through the epiploic foramen

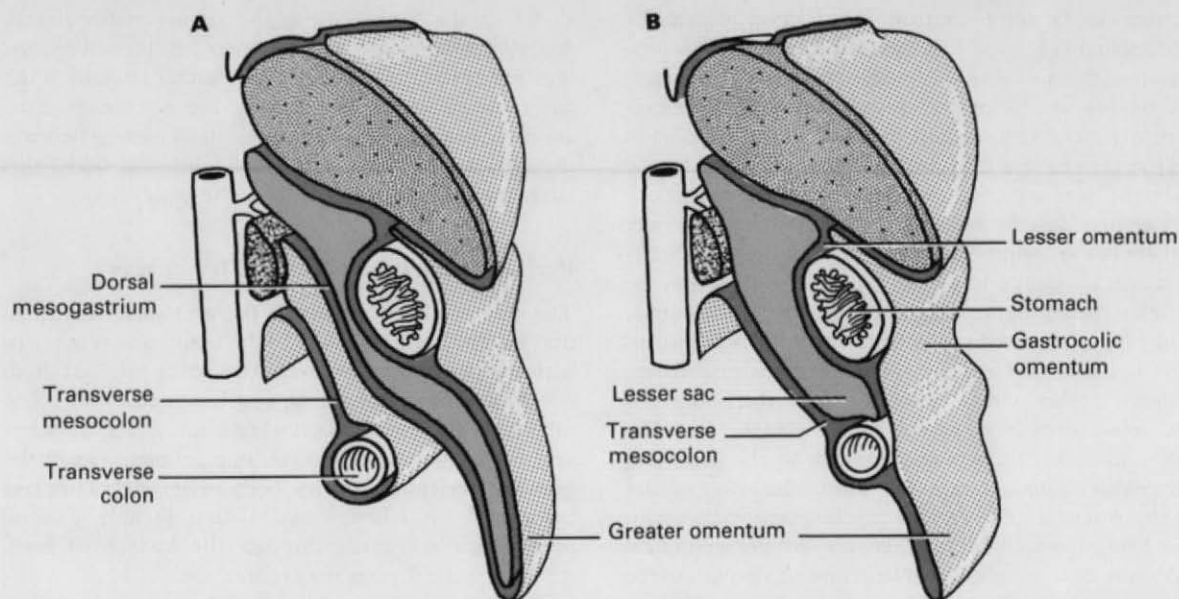


Fig. 5.16 Peritoneum of the lesser sac and greater omentum, as seen in diagrammatic sagittal sections looking towards the left. **A** The theoretical developmental condition, with the two layers of the dorsal mesogastrium overlying the two layers of the transverse mesocolon (containing the transverse colon) and forming a fold (the greater omentum) doubling back to the greater curvature of the stomach. **B** The end result, with fusion of adjacent double peritoneal layers.

cannot explore the whole of the lesser sac, but some features are palpable. Behind the posterior wall to the left of the inferior vena cava is the aorta, here giving off the coeliac trunk, two of whose branches may be felt. The common hepatic artery curves down to the right behind the peritoneum and then turns up behind the first inch of the duodenum (Fig. 5.29) to enter the lesser omentum. It raises the *pancreaticoduodenal fold*, which can be felt; to the left of the fold the fingertip passes steeply downwards behind the pylorus, as if over a step. The left gastric artery runs up towards the oesophageal opening to enter the lesser omentum; on its way up it raises the palpable *pancreaticogastric fold*. These two folds together produce a slight hourglass constriction of the sac beyond which the cavity becomes extensive, but the examining finger cannot reach its limits.

Confirm your understanding of the lesser sac by appreciating that it can be entered and more extensively explored by incising the lesser omentum and gastrocolic omentum (from the front) and the transverse mesocolon (from below) (Fig. 5.16), and the gastrosplenic and lienorenal ligaments (from the left) (Fig. 5.47).

Greater omentum

On opening the abdomen from the front, the most obvious peritoneal structure is the **greater omentum**.

It hangs down like a vascular apron from the lower border (greater curvature) of the stomach, overlying coils of intestine. It may be translucent or filled with fat, depending on the nutritional state of the individual. It is the most vascular part of the peritoneum, and is often called 'the policeman of the abdomen', since it can move to a site of infection and become adherent to it, bringing to the area protective leucocytes and 'walling off' the inflammatory region.

The greater omentum consists of two closely-applied layers of peritoneum enclosing blood vessels and lymphatics (though strictly speaking it is four layers fused together—see Fig. 5.16). The *posterior (inner)* layer is in the lesser sac, and when traced to the left it reaches the hilum of the spleen. The *anterior (outer)* layer is in the greater sac, and when traced to the left it forms the peritoneal investment for the spleen; consult Figure 5.47 and note that the two layers of peritoneum (one from the lesser sac and one from the greater sac) connecting the stomach and spleen form the *gastrosplenic ligament*, and those between spleen and kidney form the *lienorenal ligament*. Above the spleen the greater omentum passes from the back of the stomach to the diaphragm above the kidney as the *gastrophrenic ligament*. These ligaments are all derivatives of the dorsal mesogastrium (Fig. 5.20 and p. 323). The greater omentum thus has a continuous curved attach-

ment from abdominal oesophagus to duodenum, along the left and lower border of the stomach (greater curvature).

The part of the greater omentum immediately below the stomach overlies and fuses with the transverse mesocolon and transverse colon, and can be called the *gastrocolic omentum*, but it is not a separate structure—merely the name given to this upper part of the greater omentum.

Lesser omentum

The two layers of peritoneum that extend between the liver and the upper border (lesser curvature) of the stomach constitute the **lesser omentum** (sometimes called the *gastrohepatic omentum*). It can usually only be seen when the liver is lifted up, away from the stomach. Its attachment to the stomach extends from the *right* side of the abdominal oesophagus and along the *lesser* curvature to the first inch of the duodenum (Fig. 5.17). (Compare with the *greater* omentum, above: from the left side of the oesophagus and along the *greater* curvature of the stomach.) The liver attachment is L-shaped (Fig. 5.35B), to the *fissure for the ligamentum venosum* and the *porta hepatis*. Between the duodenum and the

liver it has a *right free margin*, where the peritoneum of the greater and lesser sacs becomes continuous. Within this fold are the portal vein at the *back*, with the hepatic artery in *front* and to the *left* of the vein and the bile duct to the *front* and *right* of the vein (Fig. 5.38). It is here that the portal vein forms the anterior boundary of the epiploic foramen.

The **epiploic foramen** (of Winslow, or the *aditus to the lesser sac*, Fig. 5.38) is a vertical slit about 2.5 cm (1 in) high, like the opening for a coin in a slot machine, and can be slightly stretched to admit the tips of two fingers. Its upper boundary is the caudate process of the liver (p. 345). The lower boundary is the ascending (first) part of the duodenum; this can only be understood if it is appreciated that this part of the duodenum runs not only towards the *right* but *backwards as well* (Fig. 5.29). The posterior boundary is the inferior vena cava, here covered by the parietal peritoneum of the posterior abdominal wall which, continuing to the left through the foramen, becomes the peritoneum of the posterior wall of the lesser sac. Anteriorly the foramen is bounded by the right free margin of the lesser omentum containing the portal vein, hepatic artery and bile duct (as described above); since the portal vein is the most posterior of these three structures, the

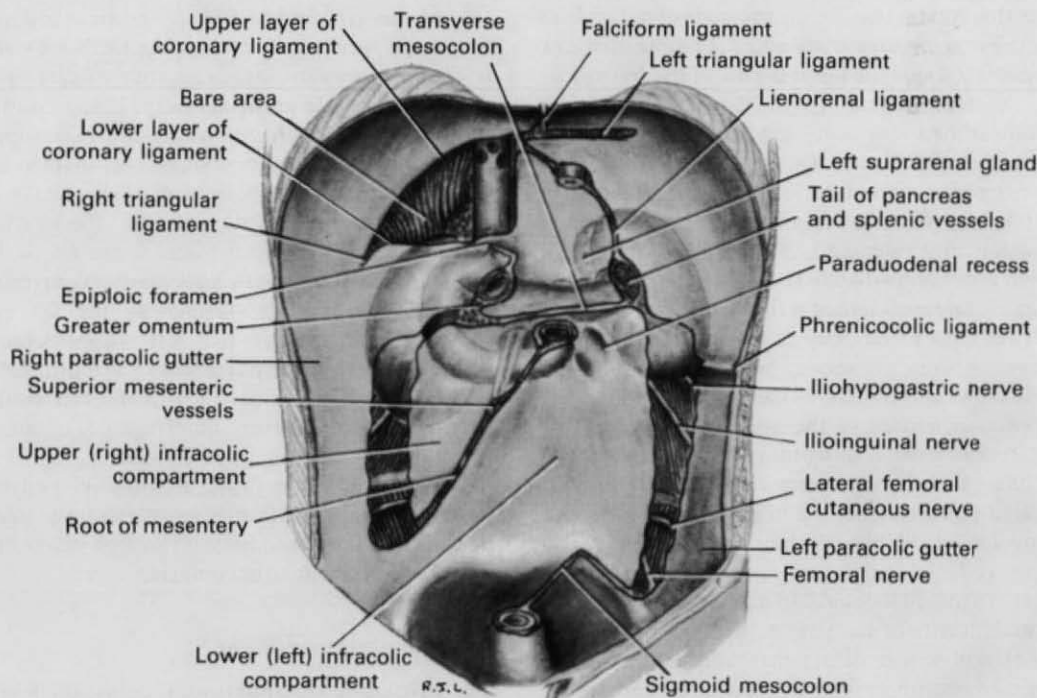


Fig. 5.17 Attachments of the parietal peritoneum to the posterior abdominal wall.

foramen can conveniently be remembered as lying *between the two great veins* of the abdomen—portal and inferior vena cava.

Traced downwards over the stomach, the two layers of the lesser omentum become greater omentum (Fig. 5.16). Traced upwards, the two layers enclose the liver and then spread on to the diaphragm and posterior abdominal wall, where they are no longer called lesser omentum but form the coronary, triangular and falciform ligaments (Fig. 5.17) which will be studied with the upper compartments of the peritoneum (below) and with the liver (p. 342).

PERITONEAL COMPARTMENTS

By virtue of its attachments to the posterior abdominal wall and to various viscera, the peritoneal cavity is descriptively divided into compartments called supracolic, infracolic and pelvic. The supracolic compartment is subdivided into four—right upper and lower, and left upper and lower, while the infracolic compartment has two parts—right (upper) and left (lower). All these are considered below; the pelvic compartment is described on page 394.

The dividing line between the supracolic and infracolic compartments is the attachment of the **transverse mesocolon** to the posterior abdominal wall, or rather to the organs that lie on the abdominal wall at this level. From Figures 5.16 and 5.17 note that the attachment is towards the lower border of the (retroperitoneal) pancreas, extending to the right over the duodenum to the lower part of the right kidney at the right colic (hepatic) flexure. On the left the attachment ends over the lower part of the left kidney at the left colic (splenic) flexure. When an opened but otherwise undisturbed abdomen is examined, this *root* of the transverse mesocolon is not immediately visible. The most obvious feature in the upper abdomen is the stomach, and below it lying over coils of intestine is the greater omentum (see above). A short distance below this curvature, the transverse colon and transverse mesocolon are adherent to the posterior surface of the greater omentum (Fig. 5.16). Lift the greater omentum up over the costal margin; the stomach, transverse colon and mesocolon will be lifted upwards with it, and the *posterior surface* of the mesocolon will be brought into view (Fig. 5.19). By displacing coils of small intestine downwards, the attachment of the mesocolon can now be seen.

The attachments of the liver to the diaphragm and abdominal wall which define the subdivisions of the supracolic compartment can be studied by comparing Figures 5.18, 5.29 and 5.35. Place the fingers of one hand *above* the liver to the *right* of the falciform

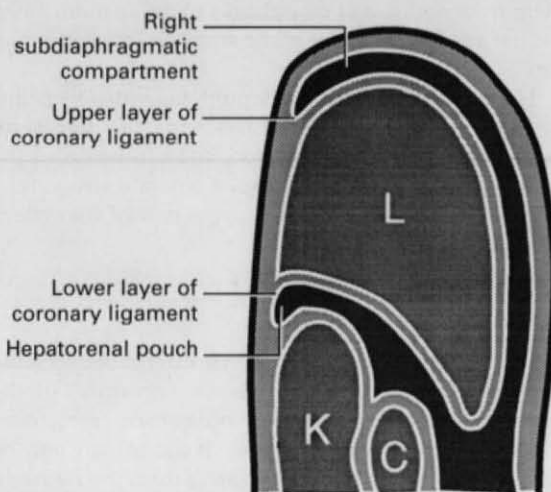


Fig. 5.18 Sagittal section through the right lobe of the liver (L), kidney (K) and transverse colon (C), showing peritoneal reflexions and the formation of the hepatorenal pouch.

ligament and push backwards. Your fingers are prevented from going further by the *upper layer of the coronary ligament*; your fingers are in the **right subphrenic (subdiaphragmatic) compartment**. Remove the hand and place the fingers *under* the right side of the liver and in *front* of the right kidney. Your fingers are prevented from going further by the *lower layer of the coronary ligament*; your fingers are in the **right subhepatic compartment**, better known as the **hepatorenal pouch** (of Morison). (The upper and lower layers of the coronary ligament meet at the right triangular ligament; these and other details of liver reflexions are considered on p. 343.) Remove the hand and now place it *above* the liver to the *left* of the falciform ligament and push backwards. Your fingers are prevented from going further by the *left triangular ligament*, and are in the **left subphrenic (subdiaphragmatic) compartment**. The fourth subdivision of the supracolic compartment is the **left subhepatic compartment**—a term not often used, because it is in fact the lesser sac, described above.

When lying supine, the hepatorenal pouch is the lowest part of the peritoneal cavity (with the sole exception of the pelvis), and hence is an area where intraperitoneal fluid is likely to accumulate.

Infracolic compartment

The **infracolic compartment**, below the level of the transverse mesocolon, is relatively easy to examine, by lifting up the stomach and greater omentum together

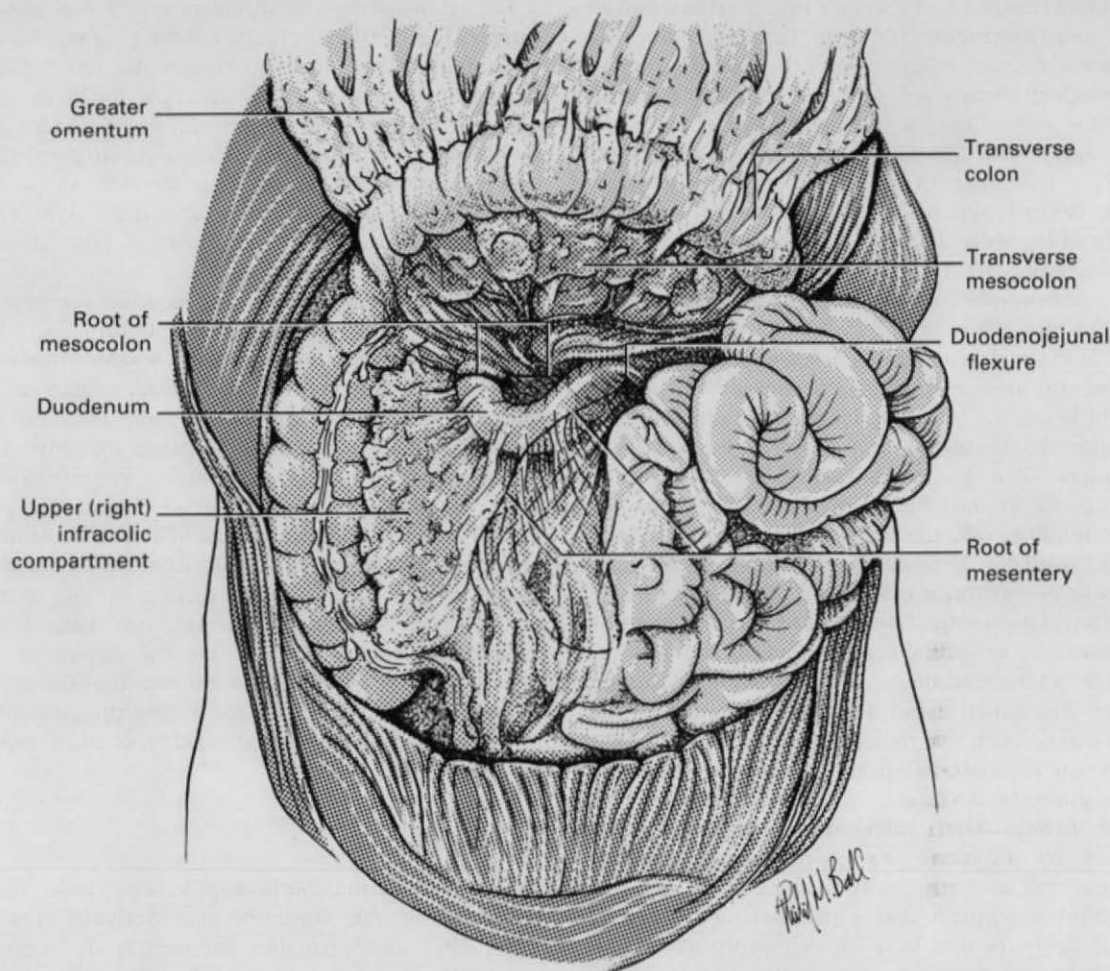


Fig. 5.19 Infracolic compartment of peritoneum. The greater omentum, transverse mesocolon and transverse colon have been lifted up and the small intestine pulled towards the left side of the peritoneal cavity, to show the root of the transverse mesocolon, root of the mesentery and the upper (right) infracolic compartment.

with the adherent transverse mesocolon and transverse colon. The whole compartment is divided into two by the attachment of the **root of the mesentery** (Fig. 5.17), which passes down from left to right at an angle of about 45° . It begins on the left at the duodenojejunal junction, crosses the third part of the duodenum where the superior mesenteric vessels enter between its two layers, and then continues downwards across the aorta, inferior vena cava, right psoas muscle and ureter to the right iliac fossa. This attachment is but 15 cm (6 in) long, although the intestinal border of the mesentery is greatly folded, like the hem of a very full skirt, to accommodate something like 3.5 metres (12 feet) of small intestine. The depth of the mesentery (from root to gut) is about 15 cm (6 in).

In the retroperitoneal tissue in the region of the root of the mesentery there are numerous Pacinian corpuscles. It is well established that tension and traction on peritoneal folds in the upper abdomen produce a fall of blood pressure by undue stimulation of these encapsulated mechanoreceptors. In normal circumstances they may serve a protective function by causing reflex contraction of the abdominal wall to aid support of the heavy viscera of the upper abdomen when jarring movements tend to displace the viscera and produce undue traction on their peritoneal attachments.

If the greater omentum is lifted up and coils of small intestine pressed downwards and to the left, a triangular area of peritoneum of the posterior abdominal wall is exposed, above and to the right of the root of the

mesentery (Fig. 5.17). This is the **upper (right) infracolic compartment**. Its apex lies below, at the ileocaecal junction. Its right side is the ascending colon, its left side the attachment of the mesentery of the small intestine, and its base is the attachment of the transverse mesocolon. Examine the floor of the triangle (Fig. 5.17). At the right end the lower pole of the right kidney can be seen and felt, crossed by the ascending branch of the right colic vessels. Just to the left of this the descending (second) part of the duodenum appears, passes downwards for 7.5 cm (3 in) and turns transversely across the posterior abdominal wall for 10 cm (4 in) as the transverse (third) part and ends by passing upwards to the duodenojejunal flexure, at which point the gut breaks free from under the peritoneum of the posterior abdominal wall and, as the jejunum, gains a mesentery. The duodenojejunal flexure, one of the angles of the left infracolic compartment, lies to the left of the midline, over the left psoas muscle, on a level with L2 vertebra. Note that to descend from the right infracolic compartment into the pelvis it is necessary to pass forwards over the lower ileum, and contrast this with the free passage into the pelvis on the left side.

Lateral to the ascending colon is the **right paracolic gutter** (Fig. 5.17). It can be traced upwards into the hepatorenal pouch (the right lower supracolic compartment), and downwards into the pelvis—easy pathways for the gravitation of fluid.

The **lower (left) infracolic compartment** is exposed by displacing the coils of small intestine upwards and to the right. It is larger than the right infracolic compartment and is quadrilateral in shape. It widens below to pass in a smooth sweep across the pelvic brim into the cavity of the pelvis (Fig. 5.17). Its upper border is the attachment of the transverse mesocolon, between the duodenojejunal flexure (to the left of the midline) and the left colic (splenic) flexure.

The fourth or ascending part of the duodenum lies in this compartment, in the upper angle to the left of the mesentery of the small intestine and it runs up to the commencement of the jejunum. The paraduodenal fossae (p. 336) lie here. At the lateral end of the upper border, the inferior pole of the left kidney can be seen and felt, in the angle between the transverse mesocolon and the splenic flexure. It is crossed by the ascending branch of the upper left colic vessels. The right border of the left infracolic compartment is provided by the attachment of the mesentery which slopes down to the right iliac fossa. The floor is shallowest in the midline, for the forward prominence of the lumbar vertebrae is here enhanced by the overlying aorta and inferior vena cava. Over the promontory of the sacrum the peritoneal floor dips down in a bold sweep to line the pelvic cavity.

Lateral to the descending colon is the **left paracolic gutter** (Fig. 5.17). It is limited above by a small transverse fold of peritoneum between the left (splenic) flexure of the colon and the diaphragm, the *phrenicocolic ligament*. Unless it has been removed by surgery (e.g. mobilizing the splenic flexure), this helps to prevent the upward spread of infection to the left subphrenic region. Traced downwards the gutter leads to the left of the left edge of the attachment of the sigmoid mesocolon and into the pelvis.

At the lower end of the left infracolic compartment is the attachment of the **sigmoid mesocolon** (Fig. 5.17). It is A-shaped and the two limbs diverge from each other at the bifurcation of the common iliac vessels, which point lies on the pelvic brim over the left sacroiliac joint. The lateral limb passes forwards along the pelvic brim (over the external iliac vessels) halfway to the inguinal ligament (i.e. about 5 cm) while the medial limb slopes down into the hollow of the sacrum, where it reaches the midline in front of S3 vertebra, at the commencement of the rectum. At the apex of the junction of these two leaves, just beneath the peritoneum and lying over the bifurcation of the common iliac artery, lies the left ureter: thus the apex is an important landmark for identifying the position of the ureter. Throw the sigmoid colon upwards to expose this point.

Nerve supply

The parietal peritoneum is supplied segmentally by the spinal nerves that innervate the overlying muscles. Thus the diaphragmatic peritoneum is supplied centrally by the phrenic nerve (C4), hence referred pain and hyperaesthesia from this area to the tip of the shoulder, and peripherally by intercostal nerves. The remainder of the parietal peritoneum is supplied segmentally by intercostal and lumbar nerves. In the pelvis the obturator nerve is the chief source of supply. The visceral peritoneum has no afferent supply as far as is known; pain from diseased viscera is due to muscle spasm, tension on mesenteric folds or involvement of the parietal peritoneum.

RETROPERITONEAL SPACE

Some major structures lie on the posterior abdominal wall behind the peritoneum. These include the aorta and inferior vena cava with a number of their branches and tributaries; the cisterna chyli, lymph nodes and vessels; nerves (mostly branches of the lumbar plexus) including the sympathetic trunks; the kidneys, ureters, pancreas, and most of the duodenum and suprarenal

glands. All these can be said to lie in the **retroperitoneal space**, though the term is often used to apply only to the area of the posterior abdominal wall behind the peritoneum that is not occupied by the major viscera and great vessels, e.g. over parts of psoas and other muscles. It is important because haemorrhage and infection may develop in it and be trapped.

PART 4 VESSELS AND NERVES OF THE GUT

The disposition of the gut and its mesenteries in the early embryo is extremely simple. The more complex arrangement in the adult is due to elongation and consequent coiling of the alimentary canal and to fusion of certain adjacent peritoneal surfaces. Some slight knowledge of the embryology is not only of value in the satisfaction of knowing how the adult arrangement

comes about, but has the considerable practical advantage of greatly clarifying understanding of the arterial supply and venous and lymphatic drainage of the whole alimentary system in the adult. The following embryological account, while true in substance, lacks accuracy in places for the purpose of simplification, and is not to be taken as a precise statement of the changes that actually occur in the growing embryo.

Gut arteries

Picture the abdominal cavity just before the sixth week of embryonic life. The alimentary canal is a simple tube passing through to the hind end, its whole length supported by a *dorsal mesentery* attached in the midline in front of the aorta (Fig. 5.20). *Three gut arteries* leave the aorta and pass ventrally to supply the tube. The most cranial passes in the *dorsal mesogastrium* to supply the foregut, the next passes through the dorsal mesentery to supply the midgut and the last passes through the dorsal mesocolon to supply the hindgut. They are

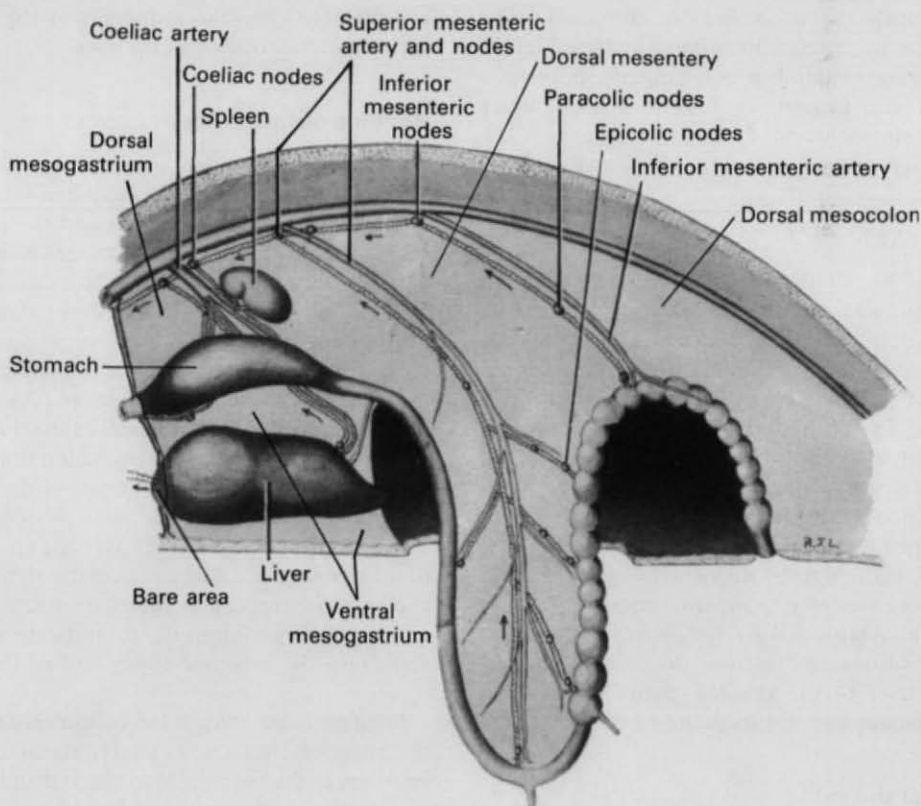


Fig. 5.20 Representation of the developing alimentary canal, viewed from the left, at the stage of herniation of the midgut. Lymphatics run back along the gut arteries to preaortic nodes.

the coeliac, the superior mesenteric and the inferior mesenteric arteries respectively, and they continue to supply the derivatives of these parts of the alimentary canal in the adult.

The foregut possesses, in addition, a *ventral mesogastrium* attached in the midline to the under surface of the diaphragm and the anterior abdominal wall down to the umbilicus (Fig. 5.20). Its free caudal edge is crescentic and carries the left umbilical vein.

The derivatives of the foregut (liver and pancreas) and also the spleen are supplied with blood by the artery of the foregut, the coeliac artery. The liver develops as an outgrowth from the foregut at its junction with the midgut. A tube grows ventrally into the ventral mesogastrium, bifurcates, and cells proliferate from the blind end of the two divisions to form the two lobes of the liver, which are thus enclosed between the two layers of the ventral mesogastrium. The pancreas develops as two outgrowths, one into the ventral and one into the dorsal mesogastrium. These two parts subsequently fuse and exchange ducts by anastomosis, but the double origin of the pancreas is imprinted on the adult by the persistence of two pancreatic ducts, the main and the accessory. The spleen develops by proliferation of cells in the left leaf of the dorsal mesogastrium. It is not, properly speaking, a derivative of the foregut itself. The coeliac artery supplies the stomach and these three organs in the adult, where it is properly called the coeliac trunk.

Lymph drainage

Lymph from the alimentary canal drains by lymph vessels that run with the arteries and end ultimately in lymph nodes that lie in front of the aorta at the roots of the three gut arteries. Lymph from the mucous membrane of the alimentary canal passes through several filters. In the mucous membrane itself, from tonsils to anal margin, are lymphoid follicles. In the mesentery, at its gut margin, are lymph nodes (the 'epi-' group, e.g. epicolic). In the mesentery between its gut margin and the root of the artery are further nodes (the 'para-' group, e.g. paracolic nodes) while the preaortic nodes, inferior mesenteric, superior mesenteric, and coeliac are interconnected by lymph vessels. All the lymph thus ultimately reaches the coeliac nodes, whence it passes to the cisterna chyli. This simple lymphatic arrangement persists in the adult.

Herniation of the gut

By the end of the sixth week the liver has enlarged greatly and the gut has elongated, both to such an

extent that the more leisurely growing abdominal walls cannot accommodate them. A loop of gut extrudes into the umbilical cord as the **physiological hernia** (Fig. 5.20). The loop remains in the umbilical cord for a full month. At the end of the tenth week the abdominal walls have grown enough to accommodate the abdominal contents and the hernia is reduced.

The herniated loop of gut is that supplied by the **superior mesenteric artery** and it is defined as the *midgut*. It is destined to produce all the small intestine from the distal part of the duodenum (i.e. distal to the entry of the bile duct) and the proximal part of the colon, almost as far as the left colic flexure. The apex of the loop is at the attachment of the vitellointestinal duct, the site of the ileal (Meckel's) diverticulum. The main trunk of the superior mesenteric artery is directed to the apex of the loop. Many branches run from it to the proximal limb of the loop, extending from the ventral pancreatic bud to Meckel's diverticulum. They persist as the jejunal and ileal branches. Only three branches run to the distal limb of the loop; all three persist in the adult as the ileocolic, right colic and middle colic arteries. Their directions are altered considerably after the reduction of the physiological hernia and the rotation of the gut.

Rotation of the midgut

As the loop of midgut in the physiological hernia returns to the abdominal cavity it rotates so that the distal limb goes up on the left and the proximal limb goes down on the right, i.e. *to the observer looking at the front of the abdomen, in an anticlockwise direction* (Fig. 5.21). The distal loop, developing into colon, thus comes to lie anterior to the commencement of the proximal loop. The commencement of the proximal loop becomes, after some rotation, plastered to the posterior abdominal wall as the duodenum, and the mesentery of the transverse colon thus comes to lie across it (Fig. 5.22). The last part of the midgut to be reincluded within the abdominal cavity is the caecum, which lies first near the midline, high up. It grows then to the right, turns downwards at the right colic flexure and stops elongating at the right iliac fossa. It leaves a trail of large intestine to indicate its migration and drags the attached lower end of the ileum with it.

Rotation of the midgut loop occurs around the axis of the superior mesenteric artery, so in the adult the branches to the *proximal* loop (jejunal and ileal arteries) come off its left side while the three branches to the *distal* loop (colic arteries) leave its *right* side (Figs 5.22 and 5.26).

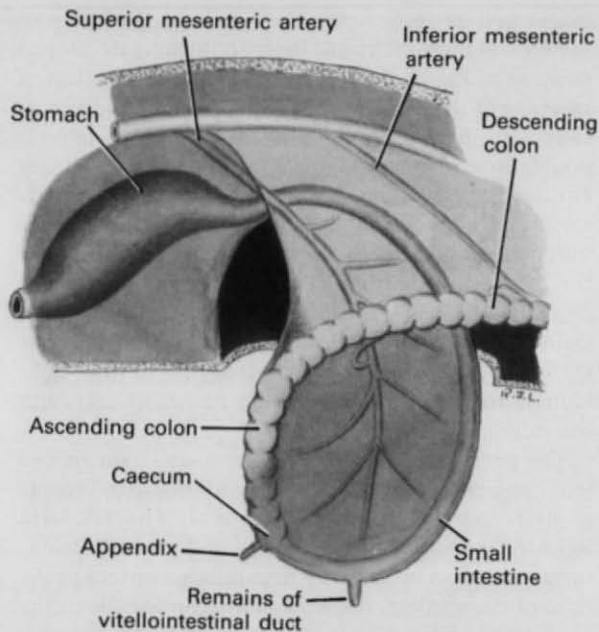


Fig. 5.21 Rotation of the midgut loop round the superior mesenteric artery, viewed from the left.

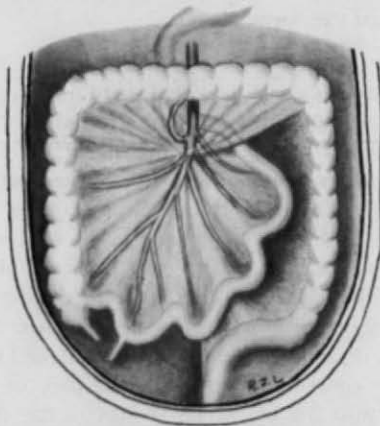


Fig. 5.22 Return of the physiological hernia and completion of rotation of the midgut, viewed from the front. The midgut loop rotates through 270°.

The simple dorsal mesentery of the midgut containing the superior mesenteric artery is, of course, much twisted and distorted during the return of the rotated loop of midgut and the subsequent migration of the caecum. Its attachment to the *proximal loop* causes it to pass across the posterior abdominal wall from the commencement of the loop (duodenum) to the ileocaecal junction. The dorsal mesentery of the *distal*

loop of the midgut hinges like a door across from the midline to the right. Its two layers come into contact with the parietal peritoneum in the right paravertebral gutter, so that three layers lie in the floor of the right infracolic compartment. The deeper two fuse and are absorbed, the anterior (originally the right) layer remaining to floor in the right infracolic compartment, with the colic vessels lying immediately deep to it and *in front of everything else on the posterior abdominal wall*. The dorsal mesentery of the most distal part of the distal loop, pulled across transversely, does not fuse completely with the parietal peritoneum and persists, with the middle colic artery between its layers, as the transverse mesocolon (Fig. 5.22).

Movement of the hindgut

As the midgut loop returns to the abdominal cavity, the hindgut swings on its dorsal mesocolon like a door across to the left (Fig. 5.23). The two layers of the mesocolon thus come to lie on the parietal peritoneum of the left paravertebral gutter. The left infracolic compartment is floored in by three layers of peritoneum. The two deeper layers fuse and are absorbed; the anterior (originally the right) layer persists, with the left colic vessels immediately beneath it and lying *in front of everything else on the posterior abdominal wall*. At the pelvic brim fusion of the layers is not complete and a small part of the intestinal edge of the dorsal mesocolon of the hindgut remains free as the sigmoid mesocolon of the adult.

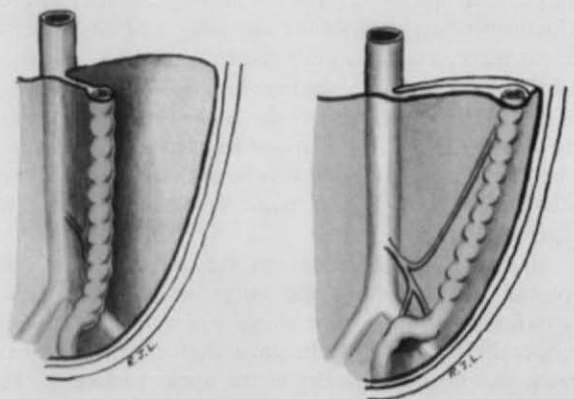


Fig. 5.23 Hindgut before and after return of the midgut hernia, viewed from the front. The mesocolon fuses with the peritoneum of the posterior abdominal wall except at the pelvic brim, where part of the embryonic mesocolon persists as the sigmoid mesocolon.

Growth of the liver

The liver grows apace, and soon outstrips the **ventral mesogastrium** in which it lies. If it had remained between the layers of the ventral mesogastrium, the peritoneal attachments would have been simple; the liver would have been surrounded equatorially by a simple line of attachment of the two leaves of peritoneum that enclose it. The double leaf of peritoneum would have been attached to the ventral border of the foregut (i.e. from oesophagus to duodenum), to the under surface of the diaphragm, and to the middle of the ventral abdominal wall down to the umbilicus. The caudal border of this peritoneal flange would have swung free from umbilicus to duodenum; at this border the peritoneum encloses the left umbilical vein from umbilicus to liver and the bile duct, hepatic artery, and portal vein from duodenum to liver (Fig. 5.20).

The growth of the liver beyond the bounds of this simple mesogastrium, and the simultaneous rotation of the stomach, tend to obscure the persisting simplicity of the peritoneal arrangements.

The liver grows caudally into the free edge of the ventral mesogastrium, which it pushes down until the umbilical vein (ligamentum teres in the adult) notches its inferior border and is enclosed in a deep groove on its under surface. This encroachment of the liver over the crescentic free margin of the ventral mesogastrium divides the latter into two separate parts, namely the *falciform ligament* between liver and anterior abdominal wall and the *lesser omentum* (gastrohepatic omentum) between liver and stomach (Fig. 5.20). The lesser omentum is attached to the liver along a fissure that runs backwards behind the fissure for the ligamentum teres, a fissure that lodges the fibrous remnant of the ductus venosus (*ligamentum venosum*), and this attachment marks the descriptive (but not the true) division of the under surface of the liver into right and left lobes. The hepatic attachment of the lesser omentum passes back to the left of the inferior vena cava, and so reaches the diaphragm. Its two leaves are attached to the diaphragm between this point and the oesophageal opening (Fig. 5.17).

Had the liver not outgrown the cranial part of the ventral mesogastrium, the latter would have been attached from this point along a simple line on the under surface of the diaphragm and anterior abdominal wall, and to the convexity of the upper surface of the liver. But this is not so. As the liver grew *caudally* to engulf the ligamentum teres it was contained within the layers of the ventral mesogastrium and merely distended them to incorporate them into its own serous coat. But the liver grows also *towards the*

diaphragm and peels apart the left and right leaves of the ventral mesogastrium. Refer to the fully developed position in Figure 5.35B, and note that the left leaf of this part of the mesogastrium (the falciform ligament) sweeps to the left and back again on itself to make a double fold, the *left triangular ligament*. The right leaf sweeps to the right and back again but these two folds are not close together; between them the liver comes into contact with the diaphragm as the *bare area*, and the folds surrounding it are the *upper layer of the coronary ligament* and the *right triangular ligament* (reflected on to the diaphragm) and the *lower layer of the coronary ligament* (reflected on to the right kidney, forming the hepatorenal pouch, p. 316 and Fig. 5.17).

The peritoneal flanges of the coronary ligament and left triangular ligament are short, and their attachments to liver and diaphragm are identical. The falciform ligament is wider, and its visceral and parietal attachments do not coincide. The liver attachment lies to the right of the midline, the parietal attachments lie in the midline; the ligament lies with its right surface against the anterior abdominal wall and its left surface against the liver.

Rotation of the foregut

Coincident with the growth of the liver, the foregut rotates. The liver originally was ventral to the foregut, in the *ventral mesogastrium*, and both lay in the midline. As the liver grows it swings to the right, taking the ventral mesogastrium with it. The stomach swings across to the left and in doing so rotates (Fig. 5.24). It has already elongated and broadened, with its dorsal border becoming convex, and its ventral border concave. The distal end of the foregut, destined to become the duodenum (i.e. proximal to the entry of the bile duct), does not dilate in this manner, and its dorsal mesentery shortens. The duodenal part of the gut elongates into a loop which swings to the right and becomes plastered to the posterior abdominal wall (like the ascending and descending parts of the colon). At the same time its walls grow asymmetrically so that the ventral bile duct and pancreatic duct are carried around to open on the medial wall (see Fig. 5.39) in line with the duct of the dorsal diverticulum. The duodenum is now fixed in position; so, too, is the oesophagus at the diaphragm. Between these two fixed points as an axis, the dorsal convexity of the stomach rotates to the left. The dorsal convexity becomes the greater curvature, and the original left side now faces anteriorly. The concave ventral border now becomes the lesser curvature, fixed by the lesser omentum (originally the ventral

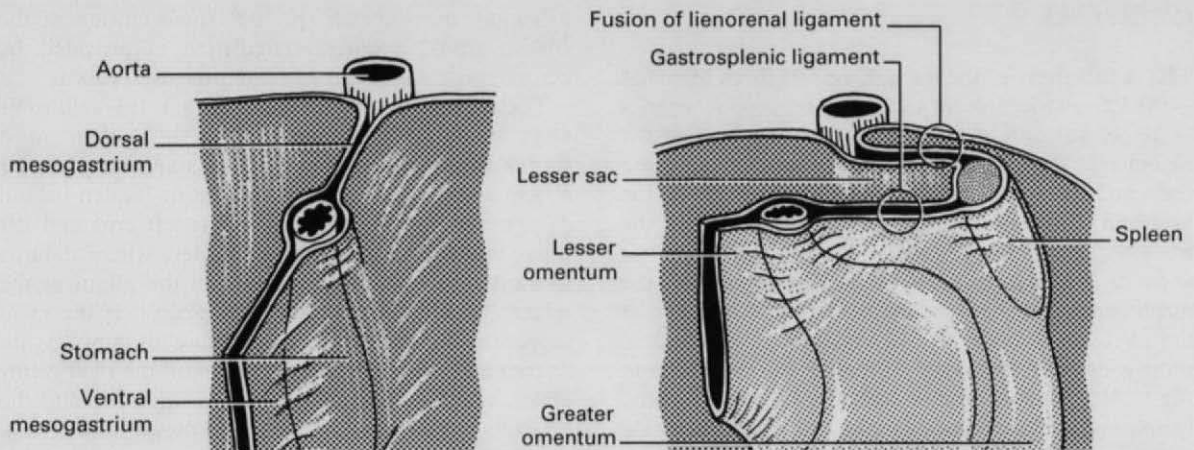


Fig. 5.24 Rotation of the stomach, viewed from the front after removal of the liver (kidney and pancreas not shown). The dorsal mesogastrium balloons down and to the left (and the spleen develops within it), and the stomach rotates through 90° so that its left surface becomes anterior, and its right surface becomes posterior, at the front of the lesser sac, with the spleen at the left margin of the sac.

mesogastrium) to the under surface of the liver, and to the diaphragm between liver and oesophagus. The original right surface of the stomach now lies behind, against the peritoneum of the posterior abdominal wall, and the free edge of the lesser omentum lies over the opening from the greater sac into this space behind the stomach, the lesser sac.

Meanwhile changes have occurred in the disposition of the **dorsal mesogastrium**. It will be remembered that it was attached to the midline of the posterior abdominal wall. As the dorsal border of the stomach swings to the left the dorsal mesogastrium hinges to the left from this attachment and adheres to the parietal peritoneum as far left as the front of the left kidney. Its left layer fuses with the peritoneum on the posterior abdominal wall and the two become absorbed (Fig. 5.24). The original right layer of the dorsal mesogastrium then lies on the posterior abdominal wall, with the left gastric and splenic branches of the coeliac artery (originally running in the dorsal mesogastrium) immediately deep to it. From the front of the left kidney, and from the diaphragm above it, the two layers of the dorsal mesogastrium pass to the oesophagus and the upper part of the greater curvature of the stomach. They form *part of the greater omentum*, and constitute the left boundary of the lesser sac behind the stomach. The spleen projects from the left leaf into the greater sac, and it divides this part of the greater omentum into *gastrosplenic* and *lienorenal ligaments* as already seen.

The fate of the *more caudal part* of the dorsal mesogastrium remains to be stated. It is attached to the

lower part of the greater curvature of the stomach, the inferior border of the pylorus and the first inch of the duodenum. Its dorsal attachment, in the midline, hinges to the left and becomes plastered to, and fused with, the peritoneum on the posterior abdominal wall over the pancreas. Below this it balloons down like an apron from the greater curvature, over the transverse mesocolon and transverse colon, and its posterior part returns to the posterior abdominal wall (Fig. 5.16A). Each part consists of the double layer of the original dorsal mesogastrium. The deeper part of the double layer fuses with the upper leaf of the transverse mesocolon and with the transverse colon itself, forming the inferior limit of the lesser sac. The superficial part of the double layer hangs down from the greater curvature directly to the transverse colon, to which it adheres, forming the anterior wall of the lower part of the lesser sac (Fig. 5.16).

From the transverse colon the two folds of the double layer hang down over the front of the coils of small intestine; adjacent leaves of peritoneum become practically fused to each other and can be separated only partially and with difficulty in the adult. They form the fat-containing apron, the **greater omentum**.

BLOOD SUPPLY OF THE FOREGUT

When the disposition of the peritoneum in the adult is clear, the course of the three ventral branches of the aorta to the gut (coeliac, superior and inferior mesenteric) can be followed simply.

Coeliac trunk

This is the artery of the foregut, and its three branches—the left gastric, splenic and common hepatic arteries—supply not only the gut from the lower part of the oesophagus down to the opening of the bile duct into the duodenum, but also the foregut derivatives (the liver and pancreas) and the spleen. It arises from the front of the abdominal aorta as soon as that vessel has entered the abdomen, between the crura of the diaphragm and behind the median arcuate ligament, at the level of the body of T12 vertebra. It is usually a short wide trunk (but may be longer, as in the scan in Fig. 5.40), flanked by the coeliac group of preaortic lymph nodes. The coeliac ganglia lie one on each side and they send to the artery sympathetic nerves which are carried along all its branches.

At the upper border of the pancreas the trunk divides into its three branches behind the peritoneum of the posterior wall of the lesser sac.

The *left gastric artery* runs upwards across the left crus towards the oesophageal opening in the diaphragm. It gives off an *oesophageal branch*, and then enters the lesser omentum to run to the right along the lesser curvature

to supply the stomach (p. 332). In occlusion of the coeliac trunk, collateral circulation is provided by oesophageal, diaphragmatic and intercostal vessels.

The **splenic artery** passes to the left. It is said to be very tortuous but is often straighter than most textbooks suggest; the crests of its waves may appear above the pancreas, and the troughs lie hidden behind its upper border. It runs across the left crus and left psoas to the hilum of the left kidney, where it turns forward in the *lienorenal ligament* to the hilum of the spleen (p. 356). Apart from the spleen it is the main supply to the pancreas (p. 353). Before breaking up into its terminal splenic branches it gives off the *short gastric arteries* which run in the *gastrosplenic ligament*, and the *left gastroepiploic artery* which runs in the *greater omentum* (p. 332).

The **common hepatic artery** passes over the upper border of the pancreas, downwards and to the right behind the peritoneum of the posterior abdominal wall (in the lesser sac) as far as the first part of the duodenum. It turns forward at the opening into the lesser sac (epiploic foramen) and curves upwards into the space between the two layers of the lesser omentum becoming the **hepatic artery**. Note this change in

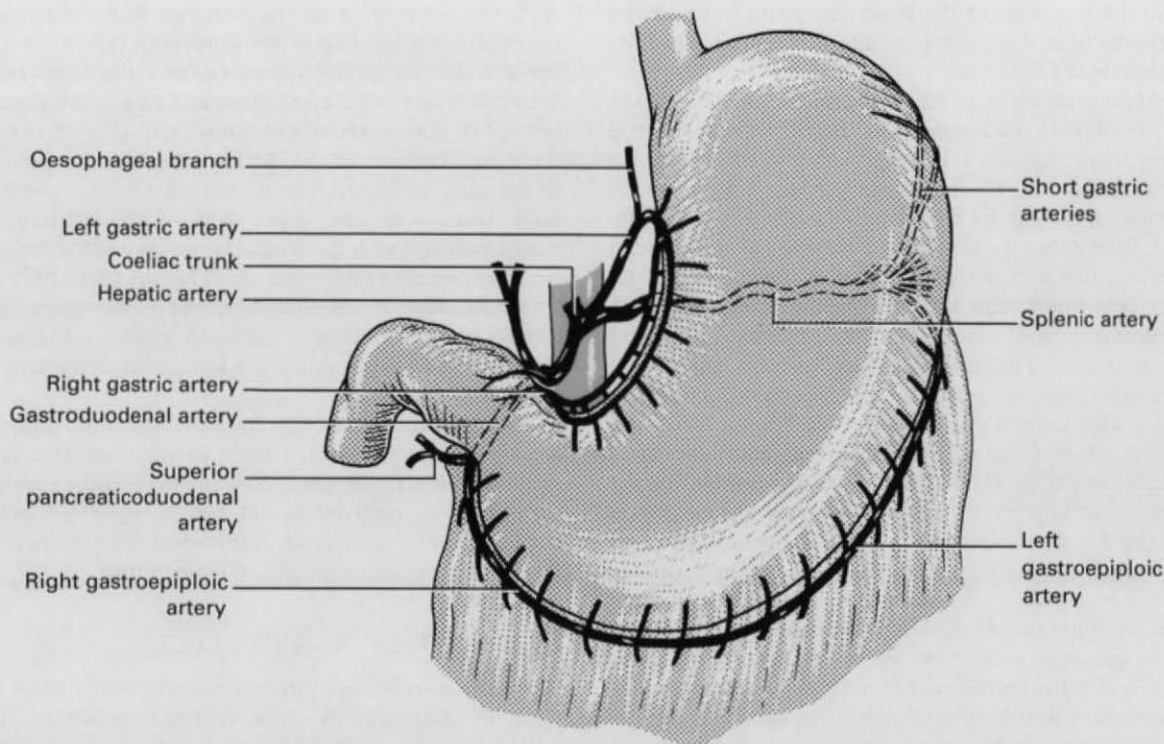


Fig. 5.25 Arterial supply of the stomach, from the three branches of the coeliac trunk.

terminology: the vessel arising from the coeliac trunk is the *common hepatic*, and it changes its name to plain *hepatic* on turning upwards. Here it meets the bile duct and lies on its left side, both in front of the portal vein. All three lie in this position, between the duodenum and the porta hepatis, surrounded by the peritoneum at the free edge of the lesser omentum. On reaching the porta hepatis, the hepatic artery divides into right and left branches to supply the right and left halves of the liver (Fig. 5.38A). These branches and the associated aberrant or accessory hepatic arteries are described on page 346.

The common hepatic usually gives off the right gastric and gastroduodenal arteries.

The **right gastric artery** leaves the common hepatic as it turns into the lesser omentum to reach the stomach (p. 332).

The **gastroduodenal artery** passes down behind the first part of the duodenum, to the left of the portal vein, and divides into two. The **right gastroepiploic artery** passes forward between the first part of the duodenum and the pancreas, and turns to the left to enter between the two leaves of the greater omentum at their attachment over the front of the head of the pancreas.

The other branch of the gastroduodenal artery is the **superior pancreaticoduodenal artery**. It divides into two branches, which encircle the head of the pancreas in the concavity of the duodenum down to the entrance of the bile duct. They consist of a small anterior and a larger posterior branch, each of which anastomoses with similar branches of the inferior pancreaticoduodenal branch of the superior mesenteric artery. The entrance of the bile duct marks the junction of foregut and midgut, and is the meeting place of the arterial distributions of the respective arteries, coeliac and superior mesenteric. The pancreaticoduodenal arteries supply the duodenum and the adjacent head of the pancreas (pp. 336 and 353).

VENOUS DRAINAGE OF THE FOREGUT

It is convenient to study the venous return with the arterial supply, for the two are essentially similar. Right and left gastric, right and left gastroepiploic veins run with the corresponding arteries. All this blood reaches the liver via the portal vein (p. 351) and, with the arterial blood of the hepatic artery, passes through the liver to be carried via the hepatic veins to the inferior vena cava.

The **superior mesenteric vein** passes up behind the pancreas and continues as the portal vein, a new name it receives after the splenic vein has joined it at a right angle behind the neck of the pancreas. The veins

of the stomach empty into the nearest part of the vertical venous channel formed by the superior mesenteric and portal veins. They correspond with the arteries of the stomach with the single exception that *there is no gastroduodenal vein*. But there is a small prepyloric vein (p. 333).

The lower third of the oesophagus in the posterior mediastinum drains downwards by **oesophageal veins**, through the oesophageal opening in the diaphragm, to the left gastric vein. The oesophagus above this level drains into the azygos system of veins. Here is a watershed from which venous blood is diverted into the systemic system and the portal system (p. 351). In portal obstruction from any cause the oesophageal tributaries of the left gastric vein become distended beneath the mucous membrane of the lower oesophagus. Such oesophageal varices may rupture and give rise to massive haemorrhage.

The **left gastric vein** runs to the left along the lesser curvature up to the oesophagus, then passes around behind the peritoneum of the posterior wall of the lesser sac, with the left gastric artery. It passes down to the right above the hepatic artery and joins the portal vein at the upper border of the pancreas. The **right gastric vein** runs along the lesser curvature to the pylorus and, to the right, behind the first part of the duodenum, it empties into the portal vein. It may receive the *prepyloric vein* if this has not drained into the portal vein.

The **short gastric and left gastroepiploic vein** run with the arteries through the gastrosplenic ligament and greater omentum to the hilum of the spleen, where they empty into the splenic vein.

The **splenic vein** begins in the hilum of the spleen by confluence of half a dozen tributaries from that organ. Having received the short gastric and left gastroepiploic veins, it passes with the tail of the pancreas, below the splenic artery, through the lienorenal ligament to lie over the hilum of the left kidney. It is a large straight vein which passes to the right in contact with the posterior surface of the pancreas (Fig. 5.29). In its course it lies on the hilum of the left kidney, the left psoas muscle and left sympathetic trunk, the left crus of the diaphragm, the aorta and superior mesenteric artery and the inferior vena cava. It lies in front of the left renal vein along the upper border of that vessel. In front of the inferior vena cava it joins the vertical trunk of superior mesenteric and portal veins at a right angle. It receives many tributaries from the tail, body, neck and head of the pancreas. As it lies in front of the left crus of the diaphragm it receives the inferior mesenteric vein from the hindgut.

The **right gastroepiploic vein** runs to the right in the greater omentum until that peritoneal structure

becomes fused to the peritoneum of the posterior abdominal wall over the head of the pancreas. It runs down over the front of the pancreas, behind the peritoneum, to join the superior mesenteric vein at the lower border of the neck of the pancreas.

The **superior pancreaticoduodenal veins** run up in the curve between the duodenum and the head of the pancreas, behind both, and join the portal vein at the upper border of the pancreas.

BLOOD SUPPLY OF THE MIDGUT

The artery of the midgut is the superior mesenteric, which supplies the gut from the entrance of the bile duct to a level just short of the splenic flexure of the colon. In the embryo it is directed to the apex of the loop of midgut in the physiological hernia (Fig. 5.21), the site of attachment of the vitellointestinal duct. This is the site of the *ileal (Meckel's) diverticulum* — in the adult it is in the ileum about 60 cm (2 feet) proximal to

the caecum and the artery terminates at this point. The rotation of the midgut loop occurs around this artery at its axis. The cranially directed branches (jejunal and ileal) to the proximal loop of the midgut thus face to the left in the adult, and the three caudally directed branches (ileocolic, right colic and middle colic) face to the right (Fig. 5.26).

The **superior mesenteric artery** arises from the front of the aorta a centimetre below the coeliac trunk, at the level of L1 vertebra. It is directed steeply downwards behind the splenic vein and the neck of the pancreas. With the superior mesenteric vein on its right side it lies on the left renal vein, then on the uncinate process of the pancreas, then on the third part of the duodenum (Fig. 5.29). Here the two vessels enter the upper end of the mesentery of the small intestine. They pass down to the right along the root of the mesentery and end at the ileum 60 cm (2 feet) proximal to the caecum (Fig. 5.26). Pressure of the superior mesenteric artery on the left renal vein may produce left-sided

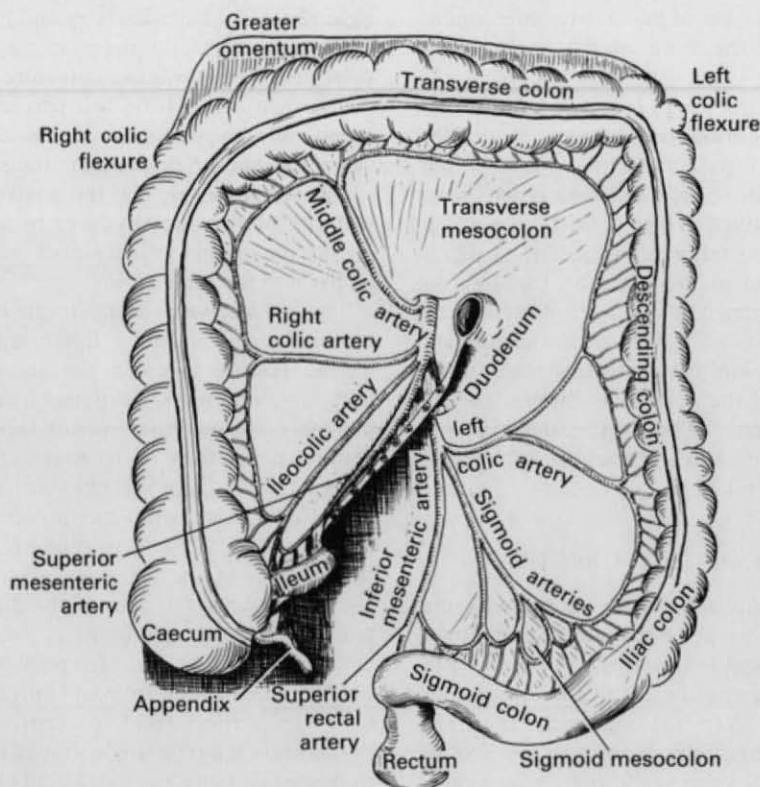


Fig. 5.26 Distribution of the superior and inferior mesenteric arteries to the large intestine. The transverse colon has been displaced upwards to expose the inferior layer of the transverse mesocolon; the middle colic artery thus appears to be running upwards, but in the normal position it passes downwards.

varicocele in either sex, and pressure on the duodenum may give symptoms of chronic duodenal ileus.

The **inferior pancreaticoduodenal artery** is its first branch, arising from the posterior surface, though it often comes off the first jejunal branch. It supplies the commencement of the midgut; that is to say, the duodenum below the entrance of the bile duct. It runs in the curve between the duodenum and the head of the pancreas, supplies both, and anastomoses with the terminal branches of the superior pancreaticoduodenal artery. The right hepatic artery occasionally arises with the inferior pancreaticoduodenal artery and runs up behind the portal vein and bile duct to supply the right half of the liver (p. 346).

The **jejunal and ileal branches** arise from the left of the main trunk and pass down between the two layers of the mesentery (Fig. 5.26). The pattern of anastomosing arcades from which vessels enter the gut wall is described with the jejunum and ileum (p. 337).

The **ileocolic artery** (Fig. 5.26) arises from the right side of the superior mesenteric trunk low down in the base of the mesentery. It runs therein to the ileocaecal junction, where it gives off an *ileal branch* which anastomoses with the terminal branch of the superior mesenteric artery and a *colic branch* which runs up along the left side of the ascending colon, behind the peritoneal floor of the right infracolic compartment, to anastomose with the right colic artery. The artery now divides into anterior and posterior caecal arteries (p. 338).

The **right colic artery** (Fig. 5.26) arises in the root of the mesentery from the right side of the superior mesenteric artery, often in common with the ileocolic artery. It runs to the right across the right psoas muscle, gonadal vessels, ureter and genitofemoral nerve, and quadratus lumborum, just behind the peritoneal floor of the right infracolic compartment. It divides near the left side of the ascending colon into two branches. The descending branch runs down to anastomose with the colic branch of the ileocolic artery. The ascending branch runs up across the inferior pole of the right kidney to the hepatic flexure where it anastomoses with a branch of the middle colic artery. From these two branches multiple vessels sink into the walls of the colon.

The **middle colic artery** (Fig. 5.26) is the highest branch from the *right* side of the superior mesenteric artery. It arises as the artery emerges at the lower border of the neck of the pancreas and passes forwards between the two leaves of the transverse mesocolon. It lies to the right of the midline and at the intestinal border of the transverse mesocolon it divides into right and left branches which run long the margin of the transverse colon. The right branch anastomoses with

the ascending branch of the right colic artery. The left branch supplies the transverse colon almost to the splenic flexure (the distal part of the midgut) where it anastomoses with a branch of the left colic artery. From these two branches multiple vessels sink into the walls of the colon. As the middle colic lies to the right of the midline it leaves a large avascular window to its left in the transverse mesocolon. This window is the site of election for surgical access to the lesser sac and the posterior wall of the stomach (Fig. 5.26). Note that in most illustrations of the middle colic artery (as in Fig. 5.26), the artery appears to be running *upwards* because the transverse colon and mesocolon have been lifted up. In life of course the vessel passes *downwards*.

VENOUS DRAINAGE OF THE MIDGUT

This is quite regular. Each branch of the superior mesenteric artery is accompanied by a vein. All these veins flow into the **superior mesenteric vein**, a large trunk which lies to the right of the artery. It crosses the third part of the duodenum, runs between the uncinate process and the neck of the pancreas to be joined by the splenic vein to form the portal vein. This continues upwards behind the first part of the duodenum. The superior mesenteric and portal veins represent a single continuing venous trunk, named portal vein above, and superior mesenteric vein below, the level of entry of the splenic vein (Fig. 5.29).

BLOOD SUPPLY OF THE HINDGUT

The artery of the hindgut is the inferior mesenteric. The muscle walls of the rectal ampulla and anal canal receive a reinforcement of arterial supply from the middle and inferior rectal arteries but the mucous membrane is supplied by the inferior mesenteric artery as far as the upper third of the anal canal.

The **inferior mesenteric artery** arises from the front of the aorta at the inferior border of the third part of the duodenum, opposite L3 vertebra, at the level of the umbilicus. It is much smaller than the superior mesenteric artery. It runs obliquely down to the pelvic brim immediately beneath the peritoneal floor of the left infracolic compartment. It crosses the pelvic brim at the bifurcation of the left common iliac vessels over the sacroiliac joint, at which point it converges on the ureter, at the apex of the Λ -shaped attachment of the sigmoid mesocolon. In its course it lies on the aorta, left psoas muscle and sympathetic trunk and the left common iliac artery, and hypogastric nerve. Over the pelvic brim it continues along the pelvic wall in the root of the sigmoid mesocolon as the **superior rectal**

artery (p. 380). It does not cross the ureter where the two meet at the pelvic brim, but all its branches cross to the left in front of the ureter and the other structures in the floor of the left infracolic compartment.

The **left colic artery** leaves the trunk and passes up to the left towards the splenic flexure, lying beneath the peritoneal floor of the left infracolic compartment. After a very short course it divides into an ascending and a descending branch. The ascending branch passes laterally and *upwards*, crossing the left psoas muscle, gonadal vessels, ureter and genitofemoral nerve, and quadratus lumborum. It is crossed by the inferior mesenteric vein. It divides into two branches. The *upper branch* passes upwards across the inferior pole of the left kidney to the splenic flexure. The *lower branch* passes transversely to the descending colon. Each of the arteries divides into ascending and descending branches which anastomose with the left branch of the middle colic artery and with each other to continue the arterial 'circle' around the concavity of the large intestine (p. 341).

The descending branch passes laterally but *downwards* crossing the same structures as the ascending branch but lower down, and divides above the pelvic brim into two or three branches. They pass to the left behind the peritoneum of the iliac fossa and supply the lower part of the descending colon and the sigmoid colon, forming anastomosing loops with each other before doing so.

The **sigmoid arteries** are three or four branches which pass forwards between the layers of the sigmoid mesocolon, in which they form anastomosing loops from which vessels sink into the wall of the sigmoid colon.

VENOUS DRAINAGE OF THE HINDGUT

The venous drainage of the rectum and anal canal is considered in detail on page 403. The superior rectal vein runs up in the root of the sigmoid mesocolon, on the left of the superior rectal artery, to the pelvic brim, above which it is named the **inferior mesenteric vein**. This receives tributaries identical with the branches of the inferior mesenteric artery. The vein itself runs vertically upwards well to the left of the artery, beneath the peritoneal floor of the left infracolic compartment. It lies on the left psoas muscle, in front of the gonadal vessels, ureter and genitofemoral nerve. At the upper limit of the left infracolic compartment, just below the attachment of the transverse mesocolon, it lies to the left of the duodenojejunal flexure. Here it curves towards the right and often raises up a ridge of peritoneum. This ridge may be excavated by a small

recess of peritoneum which makes a shallow cave beneath, the paraduodenal recess (p. 336).

The inferior mesenteric vein now passes behind the lower border of the body of the pancreas, in front of the left renal vein, and joins the splenic vein. Occasionally it curves to the right still more sharply, and, passing behind the pancreas, below and parallel with the splenic vein, in front of the superior mesenteric artery, opens directly into the superior mesenteric vein.

LYMPH DRAINAGE OF THE GASTROINTESTINAL TRACT

From the whole length of the gastrointestinal tract the lymph vessels pass back along the arteries to lymph nodes that lie in front of the aorta at the origins of the gut arteries (Fig. 5.20). These comprise the coeliac, superior mesenteric and inferior mesenteric groups of lymph nodes. They drain into each other from below upwards, the coeliac group itself draining by two or three lymph channels into the cisterna chyli.

These preaortic lymph nodes are the last in a series of lymph node filters that lie between the mucous membrane of the gut and the cisterna chyli. The first filtering mechanism consists of isolated *lymphoid follicles* which lie in the mucous membrane of the alimentary canal from mouth to anus. They are not very numerous in the oesophagus, are more numerous in the stomach, and become increasingly so along the small intestine (the GALT, p. 16). In the lower reaches of the ileum they become aggregated together into *Peyer's patches* visible through the muscular wall. These lie on the antimesenteric border of the ileum and are oval in shape, with their long axes lying longitudinally along the ileum. In the large intestine the lymphoid follicles in the mucous membrane are numerous, but isolated from each other. In the appendix they are aggregated as in a tonsil.

Lymph vessels pass from the follicles in the mucous membrane through the muscle wall of the gut to nearby nodes. The various groups of nodes are considered with the individual organs and have particular significance for the stomach and large intestine in view of the prevalence of carcinoma in these sites. However, it is convenient to note here that the small and large intestines have a common pattern of three groups of nodes. The first group lies in the peritoneum adjacent to the margin of the gut, and are known as *juxtaintestinal* nodes in the mesentery of the small intestine, and paracolic nodes for the large intestine. The second group lies along the main blood vessels of supply, and the third are the *preaortic* groups at the bases of the coeliac and the superior and inferior mesenteric vessels. The large

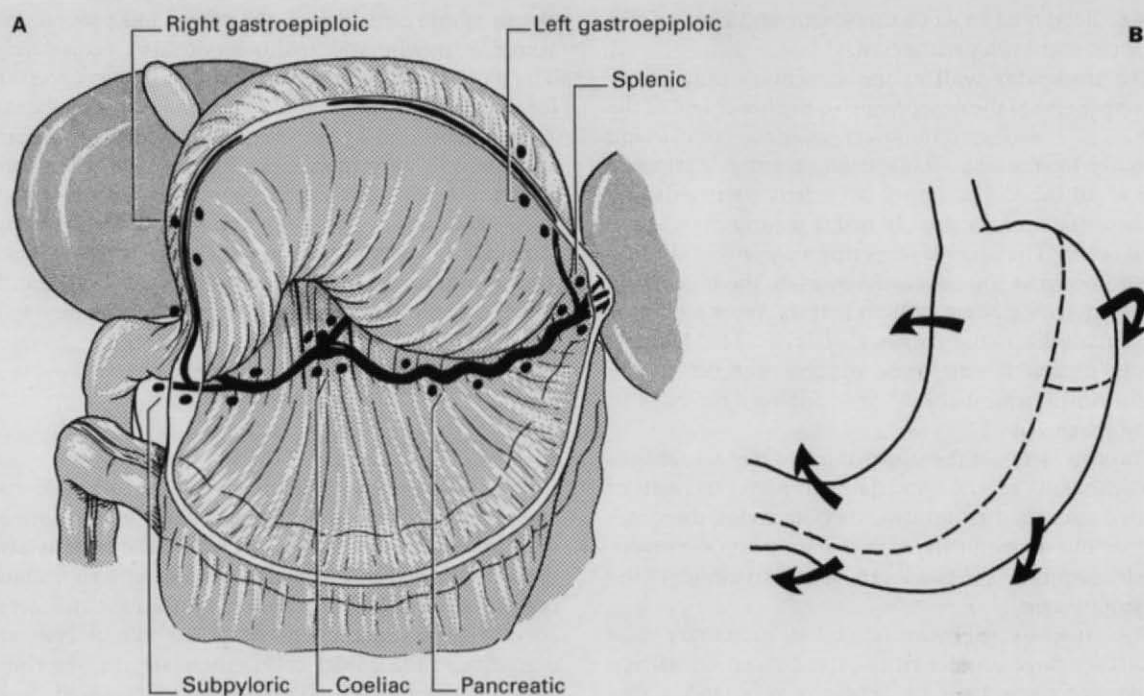


Fig. 5.27 Lymph drainage of the stomach. **A** The lesser sac has been opened up by cutting the gastrocolic omentum above the transverse colon, to show lymph nodes associated with branches of the coeliac trunk. **B** Direction of lymph flow from the stomach, as described in the text.

intestine has some additional nodes which lie on the external surface of the gut wall (and occasionally within appendices epiploicae); these are the *epicolic* nodes.

NERVE SUPPLY OF THE GASTROINTESTINAL TRACT

All parts of the gut and its derivatives are innervated by parasympathetic and sympathetic nerves, which travel together along the gut arteries to reach their destination. Most come from the coeliac plexus, but the inferior hypogastric (pelvic) plexus contributes parasympathetic fibres to the hindgut.

From the middle third of the oesophagus to the rectum, nerve cells and fibres that supply muscle, blood vessels and glands are concentrated in two plexuses. The **myenteric plexus** (of Auerbach) is situated between the two muscle layers of the gut and the **submucous plexus** (of Meissner) is in the submucosa. In the myenteric plexus the ganglion cells are usually in small groups, while in the submucous plexus they are scattered singly. Collectively the plexuses form the **enteric nervous system**, estimated to consist of 50–100 million neurons (as

many as in the spinal cord). The system receives postganglionic sympathetic (inhibitory) and pre-ganglionic parasympathetic (excitatory) fibres, but is unique in being able to function without these extrinsic efferent supplies, which do not pass directly to the gut muscle; the enteric system always intervenes. Some ganglion cells belong to afferent fibres that connect with other plexus cells or with the spinal cord (by the sympathetic trunks) and brainstem (by the vagus). The vagi below the diaphragm consist of 90% afferent fibres.

Apart from adrenergic and cholinergic neurons, others produce a variety of putative transmitters such as substance P, VIP and other neuropeptides and serotonin, whose precise functions in the normal human gut are still being unravelled.

GENERAL STRUCTURAL FEATURES

The alimentary canal has its embryological origin in the yolk sac. It is lined by epithelium derived from the endoderm, and outgrowths from this epithelium (liver and pancreas) are thus endodermal in origin.

Macroscopically the alimentary canal is a tube of

muscle lined with mucous membrane and covered, for the most part, with peritoneum.

The **muscular wall** of the alimentary canal, from the upper end of the oesophagus to the lower end of the rectum is in two separate layers, an inner circular and an outer longitudinal. This arrangement is characteristic of all tubes that empty by orderly peristalsis and not by a mass contraction. In reality the muscle is in *two spiral layers*. The inner layer forms a closewound spiral and is known as the *circular layer*, while the outer layer spirals in such gradual fashion that its fibres are virtually longitudinal, the *longitudinal layer*. The latter is mostly separated into three discrete bundles in the colon. An innermost third layer reinforces the body of the stomach.

The two layers of the upper third of the oesophagus (cervical and superior mediastinal parts) consist of striated muscle. In the lower two-thirds of the oesophagus this is gradually replaced by visceral muscle, which constitutes the two layers of the remainder of the alimentary canal.

The **mucous membrane** of the alimentary tube consists of three components: *epithelium*, an underlying connective tissue layer or *lamina propria*, and a thin layer of visceral muscle, the *muscularis mucosae*. The main features of each region are summarized below. Note that as far as identifying histological slides is concerned it is the form of the mucous membrane, and particularly the types of epithelial cells, which are the key features.

Oesophagus

The epithelium is stratified squamous non-keratinizing, like that of most of the mouth. The *muscularis mucosae*, which is absent from the uppermost part, is characteristically thicker in the oesophagus than in any other part of the alimentary tract. Small groups of mucus-secreting glands may be present at the upper and lower ends, in both the mucosa and submucosa.

Stomach

At the cardio-oesophageal junction, there is an abrupt change from stratified to single-layered columnar epithelium which continues all the way to the anal canal but with differing cell types and configuration in the different organs. Throughout, the epithelium is not a flat layer but dips down into the connective tissue *lamina propria* to form myriads of glands. In the main part of the stomach, the body, the mucus-secreting surface cells dip down to form the gastric pits which in turn continue downwards as the straight test-tube-like

glands whose cells include the peptic and parietal cells secreting pepsin and hydrochloric acid respectively. The parietal cells also secrete intrinsic factor, necessary for the intestinal absorption of vitamin B₁₂. For about a 1-centimetre ring at the cardia the glands are shorter and the cells all mucus-secreting, while in the pyloric region distal to the body the glands are like coiled test-tubes and again the cells are all mucus-secreting, although this part of the stomach contains most of the gastrin-producing endocrine G cells, as well as D cells which secrete somatostatin. Enterochromaffin (EC) cells in both body and pyloric regions produce serotonin and endorphin.

Small intestine

In the whole length of the small intestine, the columnar epithelium not only dips down to form glands (otherwise known as the crypts of Lieberkühn) but is also thrown up between the gland openings into villi, which consist of finger-like or leaf-like connective tissue cores covered by epithelium. Some of the villous cells are mucus-secreting goblet cells; others are the absorbing cells or enterocytes. Both types are derived from progenitors in the crypts and are constantly being shed and renewed, every few days. (So are other alimentary epithelial cells but at slower rates.) At the bases of the crypts are the granular Paneth cells which secrete lysozyme. Scattered among the other crypt cells are various enteroendocrine cells responsible for the production of intestinal hormones, including secretin, somatostatin and CCK, as well as EC cells.

The *duodenum* is distinguished from the rest of the small intestine in having mucus-secreting glands (of Brunner) in the submucosa. In the terminal ileum there are groups of lymphoid follicles in the mucosa forming Peyer's patches and appearing in histological sections as a row of follicles, in contrast to single follicles which can be found throughout the alimentary canal from mouth to anus.

Large intestine

In the large intestine there are no villi, only glands (crypts) containing a high proportion of goblet cells. In the appendix, which is almost invariably studied histologically as a cross-sectioned tube lined by the large intestinal type of mucosa, the glands are rather shallower and less closely packed than in the rest of the large intestine, and there are numerous lymphoid follicles in the mucosa and submucosa.

In the upper part of the anal canal, the columnar epithelium gives place to the stratified squamous type,

but here the junction is not as clear cut as the change at the cardia, and small islands of one type of epithelium may be found in an area otherwise composed of the other type.

PART 5

GASTROINTESTINAL TRACT

The alimentary canal extends from mouth to anus. Its uppermost parts — the mouth, pharynx and oesophagus — are in the head, neck and thorax; the rest is in the abdominal cavity and consists of the stomach, small intestine and large intestine, collectively known as the gastrointestinal tract (although the clinical gastroenterologist usually includes the oesophagus as well). The last 1 cm or so of the oesophagus extends through the diaphragm to join the stomach, and the last 4 cm of the tract is the anal canal which leaves the lowest or pelvic part of the abdominal cavity to lie in the perineum and open at the anus.

The abdominal **oesophagus** projects through the diaphragm at the level of the seventh costal cartilage a thumb's breadth to the left of the sternum and level with T10 vertebra. This abdominal portion is bound firmly to the margins of the diaphragmatic opening by fibrous tissue, the phreno-oesophageal ligament, and it turns forwards and to the left immediately below the opening. The anterior and posterior vagal trunks are related to the respective surfaces here (p. 334). It is invested by peritoneum which passes from it on the right to the diaphragm (the upper part of the lesser omentum) and on the left to the diaphragm (the upper part of the greater omentum). The posterior wall of the oesophagus is rather shorter than the anterior, for the orifice in the diaphragm lies very nearly vertical. This posterior part of the oesophagus can scarcely be said to possess a serous coat, for the fold of peritoneum that lies against it is not firmly attached, and is stripped up slightly when the abdominal oesophagus elongates (a miniature replica of the roof of the retropubic space — p. 381).

The oesophagus enters the stomach at the cardiac orifice. The fibres of the right crus that pass to the left of the diaphragmatic opening maintain the constant angle between the oesophagus and stomach. Various factors have been considered to guard against the reflux of gastric contents; these include the sphincteric actions of the lower oesophageal muscle fibres or the fibres of the right crus, a mucosal flap produced by the muscularis mucosae of the stomach, and the differences

between the negative intrathoracic and positive intra-abdominal pressures.

STOMACH

The **stomach** is the most dilated part of the alimentary tract, interposed between the oesophagus and duodenum in the upper part of the abdominal cavity and lying mainly in the left hypochondrial, epigastric and umbilical regions with much of it under cover of the lower ribs. It is a muscular bag, relatively fixed at both ends but otherwise subject to great variations in size depending on the volume of its contents. In the newborn it is the size of a hen's egg, with a capacity of 30 ml, but in the adult it may comfortably accommodate 1500 ml or more. The junction with the oesophagus is the **cardia** (cardiac orifice, gastro-oesophageal junction), the most fixed part of the whole organ. It lies under the diaphragm, usually to the left of the midline at the level of T10 vertebra. The distal opening is the **pyloric opening**, at the gastroduodenal junction. In the recumbent position with the stomach empty, this orifice is typically to the right of the midline at the level of L1 vertebra but may be considerably lower.

The main parts of the stomach are the fundus, body and pyloric part, with the **greater** and **lesser curvatures** forming the upper (right) and lower (left) borders (as seen from the front) and joining the anterior and posterior surfaces. The stomach is completely invested by peritoneum, which passes in a double layer from the lesser curvature to the liver as the lesser omentum, and hanging down from the fundus and greater curvature as the greater omentum, which fuses with the transverse colon and mesocolon (p. 314).

The **fundus** is the part which projects upwards above the level of the cardiac, and is in contact with the left dome of the diaphragm. It is usually full of gas (swallowed air rather than fermentation products).

The largest part of the stomach is the **body**, extending from the fundus to the **angular notch** (incisura angularis) of the lower part of the lesser curvature. This notch is a permanent feature and is not due to a transient peristaltic wave. Variable amounts of the body will be above and below the costal margin, in contact with the diaphragm and anterior abdominal wall, depending on the build and habitus of the individual and the changing volume of gastric contents. Likewise the lowest part of the greater curvature may be above or below umbilical level.

The **pyloric part** extends from the angular notch to the gastroduodenal junction, and consists of the proximal **pyloric antrum** which narrows distally as the **pyloric canal**. The circular muscle of the distal end of

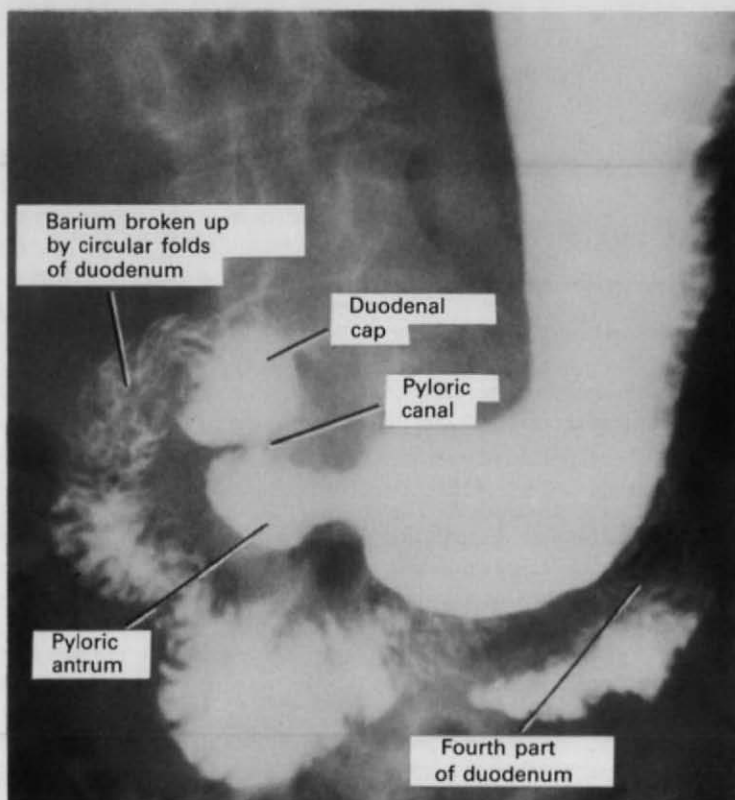


Fig. 5.28 Radiograph of the stomach and duodenum after a barium meal.

the canal is palpably thickened to form the *pyloric sphincter*, whose position is indicated on the anterior surface by the prepyloric vein, and its narrow lumen is the *pylorus* (though the word is commonly used to mean the sphincter). The pyloric canal has some mobility because it is enclosed between the peritoneum of the right extremities of the greater and lesser omenta (like the rest of the pyloric part). It hangs down over the head and neck of the pancreas. The pylorus is normally open; when a wave of gastric contraction reaches the sphincter, it contracts to squirt some gastric contents into the duodenum, but at the same time some are squeezed back into the stomach to help mix the contents.

Behind the stomach are a group of structures comprising the *stomach bed*. The posterior wall of the stomach is covered by peritoneum of the anterior wall of the lesser sac (p. 313), and the bed is covered by the lesser sac's posterior wall. Apart from the left crus and dome of the diaphragm the bed consists of the upper part of the left kidney overlaid by a triangle of structures — the pancreas transversely, with the spleen at

the upper lateral side and the suprarenal gland at the upper medial side. The transverse mesocolon slopes down from the lower border of the pancreas, while along its upper border are seen the crests of the 'waves' of the tortuous splenic artery. To the right of the lesser curvature in the midline lies the aorta with the coeliac trunk dividing into its three branches with the coeliac ganglia on either side and coeliac lymph nodes.

Blood supply

The stomach is supplied by branches from the coeliac trunk (p. 324). Along the lesser curvature between the two layers of the lesser omentum the left gastric artery anastomoses with the right gastric (usually a branch of the hepatic or gastroduodenal arteries). The fundus and upper left part of the greater curvature receive the short gastric arteries, five or six vessels which run from the splenic artery in the gastrosplenic ligament. The rest of the curvature is supplied by the left and right gastroepiploic vessels (from the splenic and gastroduo-

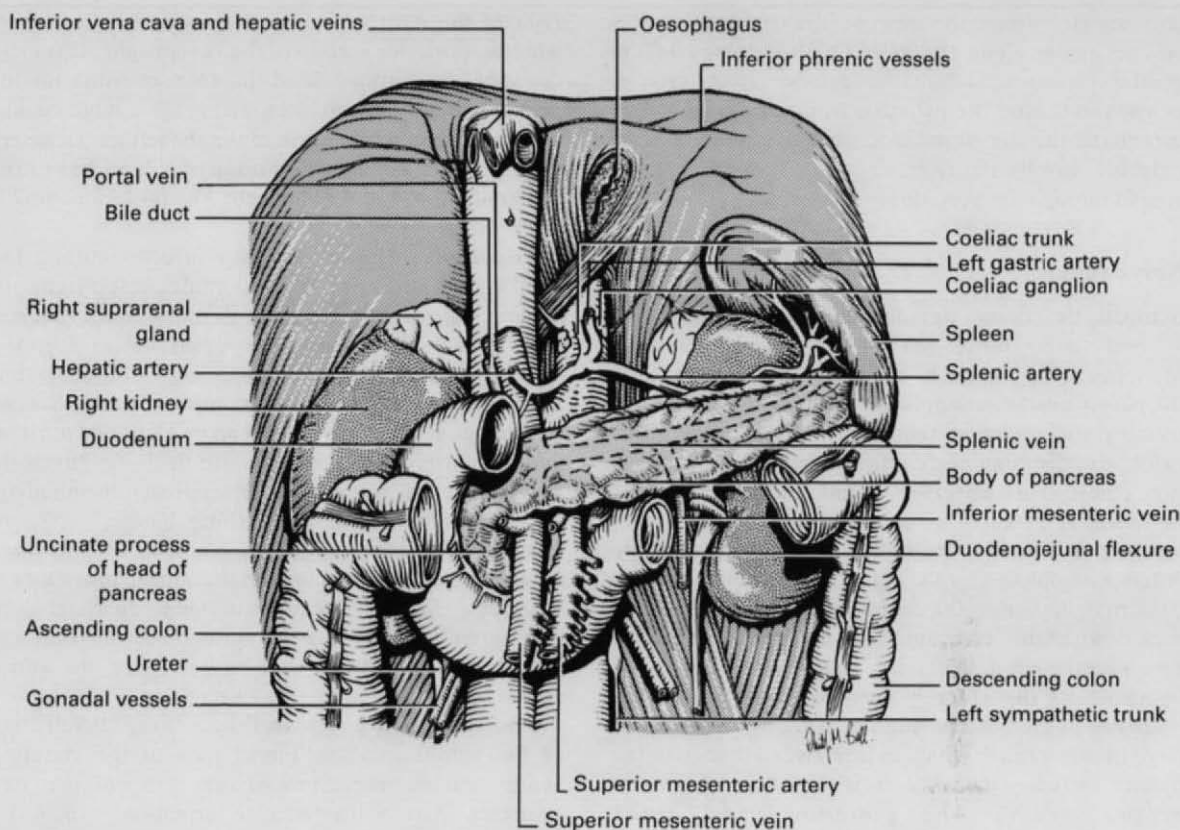


Fig. 5.29 Retroperitoneal viscera on the posterior abdominal wall.

denal arteries) running between the two layers of the greater omentum about 1 cm from the gastric wall.

The left and right gastric arteries may be double and run as two parallel branches along the lesser curvature; whether single or double they anastomose end-on with one another. So usually do the gastroepiploic vessels (they are rarely double) but sometimes their ends simply sink into the gastric wall. All these vessels give off their gastric branches at right angles (in contrast to branches from the vagal nerve trunks which come off obliquely — see below); they enter the anterior and posterior walls of the stomach. The epiploic branches of the gastroepiploics pass downwards between the leaves of the greater omentum; they are the largest of all the vessels that supply the peritoneum, ensuring that the mobile omentum receives a large supply of blood-borne phagocytes for combating infection. Although passing over the transverse colon they take no part in supplying it.

Veins of the same name accompany the arteries (except that there is no gastroduodenal vein) and drain

into the portal vein itself or its splenic and superior mesenteric tributaries (p. 351). One small vein without an accompanying artery is the prepyloric vein (of Mayo), which overlies the pylorus (to which it is a useful guide) and drains into the portal or right gastric veins.

Lymph drainage

All lymph eventually reaches coeliac nodes after passing through various outlying groups. Lymph vessels anastomose freely in the stomach wall, but there are valves in the vessels that direct lymph in such a way that a line drawn parallel to the greater curvature and two-thirds of the way down the anterior surface indicates a 'watershed' (Fig. 5.27B). From the largest zone above and to the right of this line, lymph passes to left and right gastric nodes along the lesser curvature adjacent to the blood vessels. From the upper left quadrant the lymph flows to splenic nodes at the hilum, which in turn drain to various pancreatic nodes associated with the pancre-

atic vessels. From the rest of the stomach lymph reaches nodes along the gastroepiploic vessels of the greater curvature and in the pyloric region (above, below and behind the pylorus). In rare cases of gastric carcinoma the left supraclavicular nodes may become palpably involved (*Troisier's sign*), presumably by spread through the posterior mediastinum.

Nerve supply

Sympathetic fibres (vasomotor) accompanied by afferent (pain) fibres run with the various arterial branches to the stomach, but of greater importance is the parasympathetic supply from the vagi which control motility and secretion (although 90% of vagal fibres below the diaphragm are afferent for reflex activities, not pain). The **anterior vagal trunk** (from the oesophageal plexuses — p. 261) at the oesophageal opening in the diaphragm lies in contact with the anterior oesophageal wall (Fig. 5.30), usually nearer its right margin than in the centre; in 20% it is double. It runs down in the lesser omentum near the lesser curvature with the left gastric artery (where it is often called by clinicians the anterior nerve of Latarjet), giving branches to the anterior surface of the stomach and a large hepatic branch which in turn gives a branch to the pyloric antrum. (If the nerve is double, each gives a hepatic branch.) The **posterior vagal trunk** (Fig. 5.30) lies in loose tissue a little behind and to the

right of the right oesophageal margin, not in contact with the posterior surface of the oesophagus. It runs in the lesser omentum behind the anterior trunk (as the posterior nerve of Latarjet), giving off a large coeliac branch that runs backwards along the left gastric artery to the coeliac ganglion, and numerous branches to the posterior surface of the stomach. The posterior trunk is rarely double (1%).

Vagotomy. *Truncal vagotomy* involves cutting the trunks at the level of the abdominal oesophagus. In *selective vagotomy* the branches to the stomach that run on or near the lesser curvature vessels are cut. Ligating vessels will inevitably sever some nerve branches but not all, since not all nerves accompany vessels closely, and any individual nerves that can be identified must be cut also. Arterial branches run into the lesser curvature transversely but nerve branches approach it obliquely. Although effective in diminishing gastric secretion, truncal and selective vagotomy are often accompanied by gastric stasis, so that an antral drainage procedure is required. *Highly selective vagotomy* (parietal cell vagotomy) attempts to avoid stasis by cutting only the branches to the fundus and body, leaving the antral nerves intact.

Vomiting reflex. The vagi provide the afferent side of the vomiting reflex. Fibres pass to the vomiting centre and chemoreceptor trigger zone of the area postrema (part of the reticular formation — p. 611), from which reticulospinal fibres run to anterior horn cells for activating the diaphragm and abdominal muscles. Since the area postrema is outside the blood/brain barrier (p. 600) blood-borne drugs and other substances can induce vomiting, and the reticular formation connexions with the cerebral cortex and limbic system (p. 588) account for the nausea and vomiting of emotional origin.

Structure

The main histological features are referred to on page 330. Although the angular notch is usually taken as the dividing line between the body and pyloric parts of the stomach, it is important to note that this does not necessarily indicate where the body-type of mucosa with its parietal (acid-secreting) cells gives way to the pyloric type with its concentration of G cells (producing gastrin). There is no landmark on the external surface to signal the change.

The *outer longitudinal* and *inner circular* muscle coats completely invest the stomach. They are reinforced by an incomplete *innermost oblique* muscle layer; its fibres loop over the fundus, being thickest at the notch between oesophagus and stomach. They pass along the

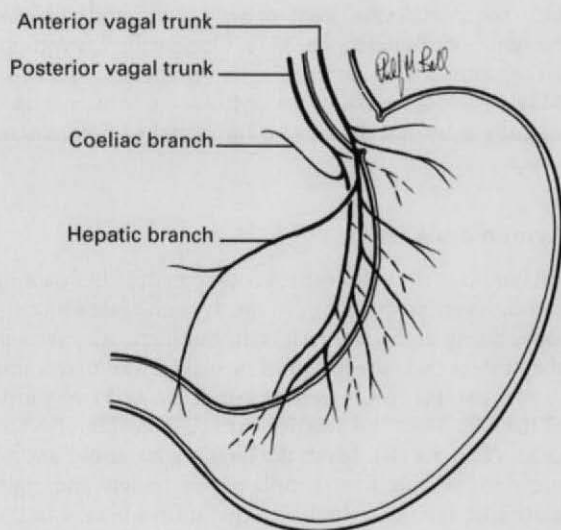


Fig. 5.30 Anterior and posterior vagal trunks and their main branches.

anterior and posterior walls in a direction oblique to the long axis of the organ, but they lie vertically when the trunk is erect, and thus obtain the best mechanical advantage for supporting the weight of gastric contents.

Gastrectomy

Partial gastrectomy (for peptic ulcer and tumour) involves removal of the distal two-thirds of the stomach, with the line of transection of the duodenum just beyond the pylorus. Among the anatomical hazards during mobilization of the stomach are the middle colic vessels, which must not be damaged when freeing the greater omentum from the adherent transverse colon and mesocolon. A gastroenterostomy to restore continuity can be made by bringing a loop of proximal jejunum through the transverse mesocolon to the left of the middle colic artery; the loop must lie isoperistaltically. The bile duct should be to the right of the line of transection of the duodenum. The left gastric artery is a larger vessel than the right gastric and should be doubly ligated. An accessory hepatic artery arising from the left gastric should be left intact; it may be the sole supply for the left lobe.

SMALL INTESTINE

The small intestine consists of the duodenum, jejunum and ileum, although clinically the term small intestine often excludes the duodenum.

DUODENUM

The **duodenum** is a C-shaped tube (Fig. 5.29) curved over the convexity of the forwardly projecting aorta and inferior vena cava. The first 2 cm are contained between the peritoneum of the lesser and greater omenta, but the remainder is retroperitoneal. It is divided into four parts. They are properly called superior, descending, horizontal and ascending, but by long tradition they are respectively and more simply called first, second, third and fourth. The total length is 25 cm (10 in), the lengths of the parts being easily remembered in inches as 2, 3, 4 and 1 but less conveniently in centimetres (5, 7.5, 10 and 2.5).

The duodenum makes its C-shaped loop round the head of the pancreas, which is classically opposite the body of L2 vertebra, so the first part may be said to lie at the level of L1 vertebra, the second on the right side of L2, the third crosses the level of L3, and the fourth is on the left of L2. The whole duodenum according to this classical textbook description is thus above umbilical level (disc between L3 and L4), but in the living

body (especially when upright) its parts may be at least one or more vertebral levels lower. The transpyloric plane (L1) is the guide to the *surface marking*.

The *first part* of the duodenum (Fig. 5.29) runs to the right, upwards and *backwards* from the pylorus; a foreshortened view is consequently obtained in sagittal radiographs (Fig. 5.28). The first 2 cm (i.e. the duodenal cap, see below) lies between the peritoneal folds of the greater and lesser omenta; it forms the lowermost boundary of the opening into the lesser sac (Fig. 5.38A). It lies upon the liver pedicle (bile duct, hepatic artery and portal vein). Behind this lies the inferior vena cava at the epiploic foramen. The neck of the gall bladder touches the upper convexity of the duodenal cap. The next 3 cm passes backwards and upwards on the right crus of the diaphragm and the right psoas muscle to the medial border of the right kidney. Its posterior surface is bare of peritoneum; this is to the right of the epiploic foramen (Fig. 5.17). It touches the upper part of the head of the pancreas and is covered in front with peritoneum of the posterior abdominal wall. The inferior surface of the right lobe of the liver lies over this peritoneum.

The *second part* of the duodenum curves downwards over the hilum of the right kidney (Fig. 5.29). It is covered in front with peritoneum, and crossed by the attachment of the transverse mesocolon, so that its upper half lies in the supracolic compartment to the left of the hepatorenal pouch (in contact with the liver) and its lower half lies in the right infracolic compartment medial to the inferior pole of the right kidney (in contact with coils of jejunum). It lies alongside the head of the pancreas, approximately at the level of L2 vertebra in a textbook cadaver, though frequently lower in life.

Its posteromedial wall receives the common opening of the bile duct and main pancreatic duct at the *hepatopancreatic ampulla* (of Vater), which opens into the lumen of the duodenum at the *major duodenal papilla*. The papilla lies about halfway along the second part, some 10 cm (4 in) from the pylorus. It is guarded by the semilunar flap of mucous membrane which surmounts it. Two cm (less than 1 in) proximal to the papilla is the small opening of the accessory pancreatic duct (at the *minor duodenal papilla*).

The *third part* of the duodenum curves *forwards* from the right paravertebral gutter over the slope of the right psoas muscle (gonadal vessels and ureter intervening) and passes over the forwardly projecting inferior vena cava and aorta to reach the left psoas muscle (Fig. 5.29). Its inferior border lies on the aorta at the commencement of the inferior mesenteric artery at the level of the umbilicus (disc between L3 and L4 verte-

brae). Its upper border hugs the lower border of the pancreas. It is covered by the peritoneum of the posterior abdominal wall just below the transverse mesocolon. It is crossed by the superior mesenteric vessels and by the leaves of the commencement of the mesentery of the small intestine sloping down from the duodenojejunal flexure. It lies, therefore, in both right and left infracolic compartments (Fig. 5.17). Its anterior surface is in contact with coils of jejunum.

The *fourth part* of the duodenum ascends to the left of the aorta, lying on the left psoas muscle and left lumbar sympathetic trunk, to reach the lower border of the pancreas, almost as high as the root of the transverse mesocolon (L2 vertebra) (Fig. 5.29). It is covered in front by the peritoneal floor of the left infracolic compartment and by coils of jejunum. It breaks free from the peritoneum that has plastered it down to the posterior abdominal wall and curves forwards and to the right as the *duodenojejunal flexure*. This pulls up a double sheet of peritoneum from the posterior abdominal wall, the mesentery of the small intestine, which slopes down to the right across the third part of the duodenum and posterior abdominal wall (Fig. 5.17).

It is the peritoneal attachment which distinguishes duodenum and jejunum. The duodenum is retroperitoneal, the jejunum has a mesentery (compare junction of rectum and sigmoid colon).

The duodenojejunal flexure is fixed to the left psoas fascia by fibrous tissue. It is said to be further supported by the *suspensory muscle of the duodenum* (muscle or ligament of Treitz). This is a thin band of smooth muscle; it descends from the right crus of the diaphragm in front of the aorta, behind the pancreas but in front of the renal vessels, and blends with the outer muscle coat of the flexure. It is often impossible to find the muscle.

Internally the mucous membrane of most of the duodenum, like the rest of the small intestine is thrown into numerous circular folds (*plicae circulares* or *valvulae conniventes*). But the walls of the first 2 cm are smooth, hence the *smooth* outline of the full shadow of barium in the 'duodenal cap' at radiographic examination (Fig. 5.28). From the duodenal cap onwards the *plicae* break up the barium and its shadow.

Histological details are referred to on page 330.

Paraduodenal recesses. To the left of the duodenojejunal flexure certain peritoneal folds and evaginations (recesses or fossae) are occasionally present. The most important surgically is the *paraduodenal recess* proper (Fig. 5.31). This is a small evagination of peritoneum beneath the upper end of the inferior mesenteric vein; an incarcerated hernia in this fossa may obstruct and thrombose the vein, and there is

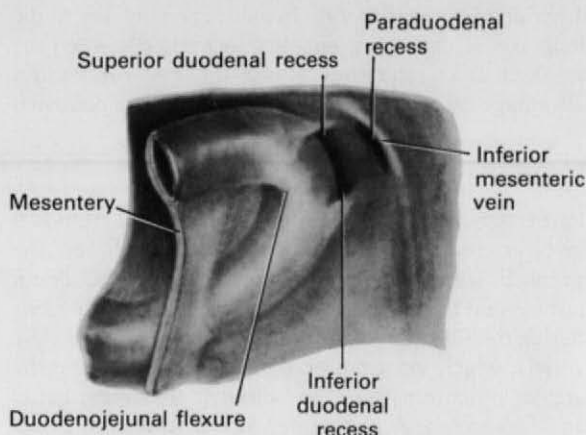


Fig. 5.31 Peritoneal recesses of the duodenum. They are only occasionally present. The paraduodenal recess has the inferior mesenteric vein at the front of its opening.

danger of dividing the vein if the peritoneum has to be divided at operation to free the hernia. Folds of peritoneum may rise from the floor of the infracolic compartment to both upper and lower convexities of the flexure; the fossae beneath such folds are known as the *superior duodenal* and *inferior duodenal* recesses respectively. Finally a *retroduodenal* recess may be excavated behind the flexure, between the superior and inferior recesses. The recesses are frequently called fossae.

It should be noted that the mouths of these four recesses all face inwards *towards* each other, and a hernia in any one may thus spread to involve others. This is not so with the caecal recesses, whose mouths all face *away from* each other (p. 339).

Blood supply

The duodenum is supplied by the superior and inferior pancreaticoduodenal arteries (p. 325), but the first 2 cm, clinically so important because of ulceration here, receive small branches from a variety of sources: hepatic, common hepatic, gastroduodenal, superior pancreaticoduodenal, right gastric and right gastroepiploic. There are corresponding veins, with some blood also entering the small prepyloric vein (p. 333).

Lymph drainage

Duodenal lymph drains by channels that accompany the superior and inferior pancreaticoduodenal vessels to coeliac and superior mesenteric nodes.

JEJUNUM AND ILEUM

The jejunum is wider-bored and thicker-walled than the ileum; but these differences are only relative, and a more useful method of distinguishing one from the other in the living is by rolling the wall of the intestine gently between finger and thumb. The wall of the jejunum is thick and double (the mucous membrane can be felt through the muscle wall, 'a shirt sleeve felt through a coat sleeve'), while the wall of the ileum is thin and single (the mucous membrane cannot be felt as a separate layer).

The lower reaches of the ileum are distinguished by the presence on the antimesenteric border of elongated whitish plaques in the mucous membrane, usually but not always visible through the muscle wall. These are the aggregated lymphoid follicles (Peyer's patches). The jejunum lies coiled in the upper part of the infracolic compartment, the ileum in the lower part thereof and in the pelvis.

The jejunum and ileum together lie in the free margin of the mesentery. Total length varies greatly, from about 4 to 6 metres (13 to 20 feet) in the living. The jejunum constitutes rather less than half the total length, say two-fifths, allowing three-fifths for the ileum.

An **ileal (Meckel's) diverticulum** is present in 2% of individuals, 60 cm (2 feet) from the caecum and is 5 cm (2 in) long. This useful mnemonic is two-thirds true; the length of the diverticulum is very variable. Its blind end may contain gastric mucosa or liver or pancreatic tissue. It represents the intestinal end of the vitellointestinal duct, and its apex may be adherent to the umbilicus or connected thereto by a fibrous cord, a further remnant of the duct. Ulceration and perforation of the tip can occur.

Blood supply

Numerous jejunal and ileal branches arise from the left side of the superior mesenteric artery (p. 327) and enter the mesentery by passing between the two layers of the root. The jejunal branches join each other in a series of anastomosing loops to form *arterial arcades* — single for the upper jejunum and double lower down. From the arcades, *straight arteries* pass to the mesenteric border of the gut (Fig. 5.32). These vessels are long and close together, forming high narrow 'windows' in the intestinal border of the mesentery, visible because the mesenteric fat does not reach thus far. The straight vessels pass to one or other side of the jejunum and sink into its wall. Occlusion of a straight artery may lead to infarction of the segment supplied because these are end arteries, but occlusion of arcade vessels is usually

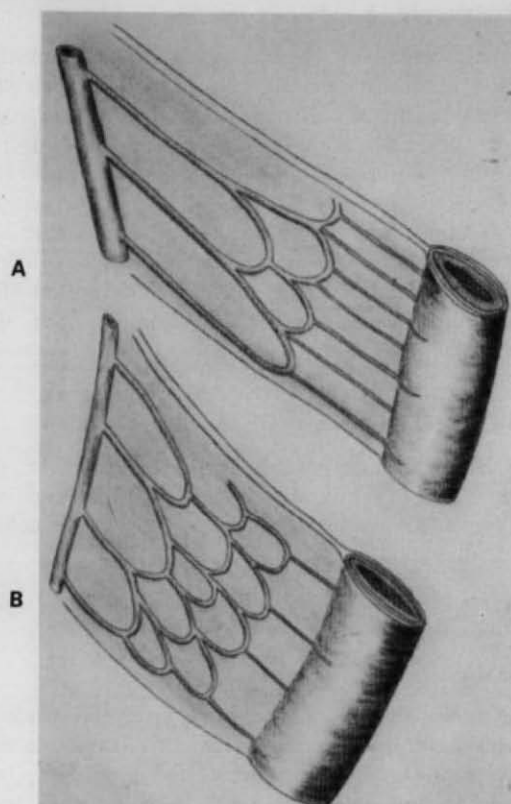


Fig. 5.32 Arcades of the superior mesenteric artery: **A** in the jejunum; **B** in the ileum. Compare the high narrow windows between the vasa recta running to the wall of the jejunum with the low broad windows between those of the ileum.

without effect due to their numerous anastomotic connexions.

The ileal arteries are similar but form a larger series of arcades — three to five, the most distal lying near the ileal wall so that the straight vessels branching off the arcades are shorter. There is more fat in this part of the mesentery, so the windows characteristic of the jejunal part are not seen — a useful feature in identifying loops of bowel.

The end of the superior mesenteric artery itself supplies the region of the ileal diverticulum (if present), and anastomoses with the arcades and with the ileocolic branch to supply the terminal ileum.

The veins all correspond to the arteries and thus drain to the superior mesenteric.

Lymph drainage

Jejunal and ileal lymph drains to superior mesenteric nodes via the groups already described (p. 328).

Nerve supply

The parasympathetic vagal supply of the small intestine reaches the intestinal wall with its blood vessels and normally augments peristaltic activity. There are many afferent fibres whose function is unknown; they do not transmit pain impulses which, as with the stomach and other viscera, use sympathetic pathways. The sympathetic supply, which is vasoconstrictor and normally inhibits peristalsis, is from the lateral horn cells of spinal segments T9 and 10; small intestinal pain is usually felt in the umbilical region of the abdomen. See also page 329.

LARGE INTESTINE

The large intestine consists of the caecum with the worm-shaped (vermiform) appendix, the ascending, transverse, descending and sigmoid parts of the colon, the rectum and the anal canal.

CAECUM AND APPENDIX

Caecum

This blind pouch of the large intestine projects downwards from the commencement of the ascending colon, below the ileocaecal junction (Fig. 5.33A). Over the front and on both sides it is covered with peritoneum. The serous coat continues up behind it and is reflected downwards to the floor of the right iliac fossa. The retrocaecal peritoneal space may be shallow or deep according to the distance of the retrocaecal fold from the lower end of the caecum. The space may be continuous across the iliac fossa or it may be interrupted by a peritoneal fold from one or other side of the posterior wall of the caecum. Often there are two caecal folds, forming between them the *retrocaecal recess* in which the appendix may lie. As in the rest of the colon, the longitudinal muscle of the caecum is concentrated into three flat bands, the taeniae coli, between which the circular muscle layer constitutes the sacculated wall of the gut. The taeniae lie one anterior, one posteromedial and one posterolateral. All three converge on the base of the appendix — a useful guide.

Internally the ileocaecal junction is guarded by the *ileocaecal valve* (Fig. 5.33B), whose almost transverse lips may help to prevent some reflux into the ileum, but any possible sphincteric action is poor.

In the infant the caecum is conical and the appendix extends downwards from its apex. The lateral wall outgrows the medial wall and bulges down below the base of the appendix in the adult; the base of the appendix thus comes to lie in the posteromedial wall of

the caecum above its lower end, and the three taeniae converge to this point (Fig. 5.33). The terminal inch or so (say 2 cm) of the ileum is commonly adherent to the left convexity of the caecum, below the ileocaecal junction.

The caecum lies on the peritoneal floor of the right iliac fossa, over the iliacus and psoas fasciae and the femoral nerve. Its lower end lies at the pelvic brim. When distended its anterior surface touches the parietal peritoneum of the anterior abdominal wall; when collapsed coils of ileum lie between the two.

Blood supply. Various branches of the anterior and posterior caecal vessels fan out over the respective sides of the caecum. The anterior caecal artery is the smaller of the two terminal branches of the ileocolic artery (p. 327), and ramifies over the anterior surface. The posterior caecal artery is larger and supplies the rest of the caecum, and it also usually gives off the appendicular artery. There are corresponding veins.

Lymph drainage. Lymph passes to nodes associated with the ileocolic artery (p. 328).

Appendix

The appendix is a worm-shaped, blind-ending tube (Fig. 5.33) varying in length from 2 to 25 cm (commonly about 6 to 9 cm), which opens into the posteromedial wall of the caecum 2 cm below the ileocaecal valve (Fig. 5.33B). Externally the *base* of the appendix is at the point of convergence of the three taeniae coli on the posteromedial wall of the caecum (an important guide in appendicectomy, see below). On the surface of the abdomen this point (McBurney's) lies one-third of the way up the oblique line that joins the right anterior superior iliac spine to the umbilicus. The three taeniae merge into a complete longitudinal muscle layer for the appendix. While the position of the *base* of the appendix is constant in relation to the caecum (though perhaps a little lower than McBurney's point), the *tip* may lie in a variety of positions (Fig. 5.33C). The commonest as found at operation are the retrocaecal and retrocolic positions, but recent scanning studies suggest that a retroileal site is the commonest in the absence of disease. The appendiceal lumen is relatively wide in the young child but may be obliterated in old age.

The appendix has its own short mesentery, the **mesoappendix**, which is a triangular fold of peritoneum and is a prolongation of the left (inferior) layer of the mesentery of the terminal ileum (Fig. 5.33A).

Blood supply. The appendicular artery is normally a branch of the posterior caecal (and may be double). It runs first in the free margin of the mesoappendix and

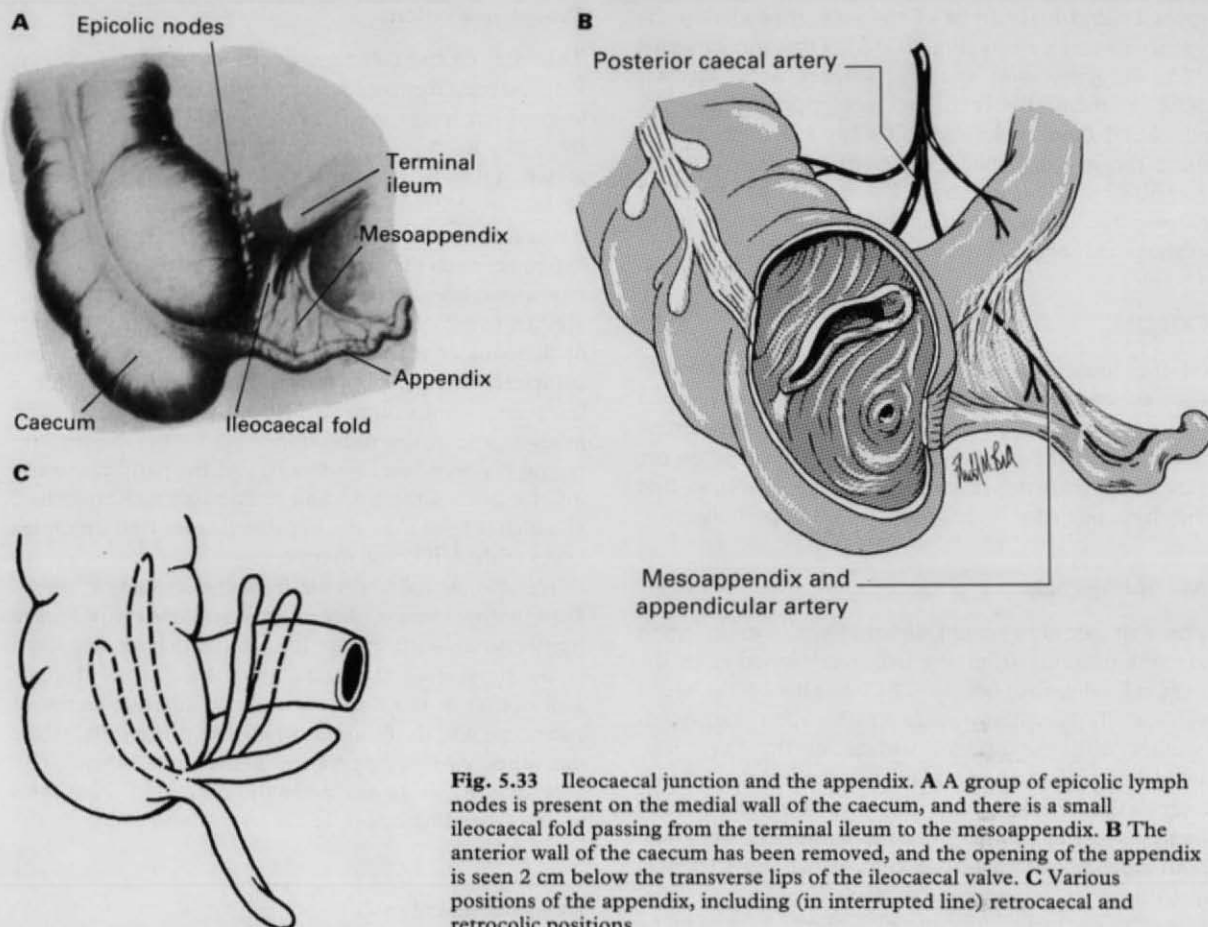


Fig. 5.33 Ileocaecal junction and the appendix. **A** A group of epiploic lymph nodes is present on the medial wall of the caecum, and there is a small ileocaecal fold passing from the terminal ileum to the mesoappendix. **B** The anterior wall of the caecum has been removed, and the opening of the appendix is seen 2 cm below the transverse lips of the ileocaecal valve. **C** Various positions of the appendix, including (in interrupted line) retrocaecal and retrocolic positions.

then close to the appendicular wall. Inflammatory swelling of the distal part of the organ may thus obstruct the vessel, leading to ischaemic necrosis and perhaps rupture of the appendix; there is no collateral circulation, for the appendicular artery is an end artery (unlike the cystic artery of the gall bladder, which is supplemented by vessels from the gall bladder bed, (p. 348). There are corresponding veins.

Lymph drainage. As from the caecum lymph passes to nodes associated with the ileocolic artery (p. 328).

Appendicectomy. Through a McBurney or transverse muscle-splitting incision (p. 311), the peritoneal cavity is opened and the whole length of the appendix identified. If it is not immediately obvious, tracing any of the taeniae down over the caecal wall will lead to the base of the appendix. The whole organ is mobilized, often requiring very delicate loosening of adhesions, and the mesoappendix divided before the base is

crushed and divided and the rest of it removed. The stump is invaginated with a pursestring suture.

Caecal recesses

Apart from the caecal folds that form the retrocaecal recess (p. 338), other small peritoneal folds are often found in the region of the terminal ileum, caecum and base of the appendix, forming further recesses or fossae. The most anterior fold lies in front of the terminal ileum between the base of the mesentery and the anterior wall of the caecum, and is raised up by the contained anterior caecal artery; hence the fold is called the *vascular fold of the caecum*. The space behind it is the *ileocaecal recess*. Another fold may run from the terminal ileum towards the base of the appendix and mesoappendix. This is the *ileocaecal fold* (formerly called the 'bloodless fold of Treves', but this is a misnomer as it frequently contains small vessels) (Fig. 5.33A), and the

space behind it (in front of the mesoappendix) is the *inferior ileocaecal recess* (Fig. 5.33A). Thus three parallel folds of peritoneum enclose two ileocaecal recesses between them. Between the mesoappendix and the peritoneal floor of the right iliac fossa there is often a third recess and, finally, the retrocaecal fossa when present constitutes a fourth. The mouths of these four recesses face away from each other, unlike the mouths of the paraduodenal fossae (p. 336).

COLON

Of the four parts of the colon, the transverse and sigmoid parts are suspended in mesenteries — the transverse mesocolon and sigmoid mesocolon respectively — but the ascending and descending colon are plastered on to the posterior abdominal wall so that they have posterior 'bare areas' devoid of peritoneum.

Ascending colon

This first part of the colon, about 15 cm (6 in) in length extends upwards from the ileocaecal junction to the right colic (hepatic) flexure. The latter lies on the lateral surface of the inferior pole of the right kidney, in contact with the inferior surface of the liver. The ascending colon lies on the iliac fascia and the anterior layer of the lumbar fascia, being connected and fixed to them by extraperitoneal fibrous tissue. Its front and both sides possess a serous coat, which runs laterally into the paracolic gutter and medially into the right infracolic compartment. Its original embryonic mesentery, which is retained in about 10% of adults, hinged across from the midline and became adherent to the peritoneum of the posterior abdominal wall, bringing the ileocolic and right colic vessels within its folds. These vessels thus lie, in the adult, immediately beneath the peritoneum of the right infracolic compartment.

The *taeniae coli* lie, in line with those of the caecum, anteriorly, posterolaterally and posteromedially. These consist of longitudinal muscle fibres and the circular muscle coat is exposed between them. The ascending colon is sacculated, due to the three *taeniae* being 'too short' for the bowel. If the *taeniae* are divided between the sacculations the latter can be drawn apart and the bowel wall flattened.

Bulbous pouches of peritoneum, distended with fat, the *appendices epiploicae*, project in places from the serous coat. The blood vessels supplying them from the mucosa perforate the muscle wall. Mucous membrane may herniate through these vascular perforations, a condition known as *diverticulosis*. *Diverticulitis* is inflammation of these mucosal herniae.

Transverse colon

This part of the colon, normally over 45 cm (18 in) long, extends from the hepatic to the splenic flexure in a loop which hangs down to a variable degree between these two fixed points. It is in contact with the anterior abdominal wall. The convexity of the greater curvature of the stomach lies in its concavity, the two being connected by the gastrocolic omentum. Because of the fusion between the greater omentum and the transverse mesocolon and transverse colon, the greater omentum appears to hang down from its lower convexity, in front of the coils of small intestine. The transverse colon is completely invested in peritoneum; it hangs free on the transverse mesocolon, which is attached from the inferior pole of the right kidney across the descending (second) part of the duodenum and the pancreas to the inferior pole of the left kidney. The splenic flexure lies, at a higher level than the hepatic flexure, well up under cover of the left costal margin.

The *taeniae coli* continue from the ascending colon. Due to the looping downwards and forwards of the transverse colon from the flexures, which lie well back in the paravertebral gutters, some rotation of the gut wall occurs at the flexures, and the anterior *taenia* of ascending and descending colons lies posteriorly, while the other two lie anteriorly, above and below. The *appendices epiploicae* are larger and more numerous than on the ascending colon.

Descending colon

Less than 30 cm (12 in) long, this extends from the splenic flexure to the pelvic brim, and in the whole of its course is plastered to the posterior abdominal wall by peritoneum (like the ascending colon), though a mesentery is present in about 20% of adults. It lies on the lumbar fascia and the iliac fascia, being connected to them by extraperitoneal fibrous tissue. It ends at the pelvic brim about 5 cm (2 in) above the inguinal ligament.

The *three taeniae coli*, in continuity with those of the transverse colon, lie one anterior and two posterior (medial and lateral). *Appendices epiploicae* are numerous and diverticulosis is common in this part of the colon.

In the embryo the descending colon possessed a midline dorsal mesocolon containing the left colic vessels between its layers. The mesocolon hinged to the left like a door and became fused with the parietal peritoneum of the posterior abdominal wall (Fig. 5.23); thus in the adult the peritoneal floor of the left infracolic compartment is the right leaf of the original dorsal mesocolon, and the left colic vessels lie immediately beneath it.

Sigmoid colon

Formerly known as the pelvic colon, this extends from the descending colon at the pelvic brim to the commencement of the rectum in front of the third piece of the sacrum. It is completely invested in the peritoneum (like the transverse colon) and hangs free on a mesentery, the sigmoid mesocolon. It is usually less than 45 cm (18 in) long, though great variations in length are common. There is no change in the gut wall between terminal sigmoid colon and upper rectum; the distinction is only for peritoneal attachment. Where there is a mesentery the gut is called sigmoid. Where the mesentery ceases the gut is called rectum. Compare with the duodenojejunal junction (p. 336).

Like the rest of the large intestine, the commencement of the sigmoid colon is sacculated by three taeniae coli, but these muscular bands are wider than elsewhere in the large gut, and meet to clothe the terminal part of the sigmoid in a complete longitudinal coat. The sigmoid colon possesses well-developed appendices epiploicae, and diverticulosis is commonest in this part of the colon. It lies, usually, in the pelvic cavity, coiled in front of the rectum, lying on the peritoneal surface of the bladder (and uterus).

The *sigmoid mesocolon* in the embryo had originally a midline dorsal attachment. It hinged to the left like that of the descending colon and became partially, but not completely, fused with the parietal peritoneum of the posterior abdominal and pelvic wall. The part remaining free is joined to the parietal peritoneum along a Λ -shaped base (Fig. 5.17). The limbs of the Λ diverge from the bifurcation of the common iliac artery, over the sacroiliac joint at the pelvic brim. The lateral limb is attached to the external iliac artery along the pelvic brim from this point halfway to the inguinal ligament, a distance of about 5 cm (2 in). The medial limb extends from the bifurcation of the common iliac artery to the midline of the posterior pelvic wall at the level of the third piece of the sacrum, for about the same distance. The base of the sigmoid mesocolon thus measures about 10 cm (4 in) but its intestinal border and therefore the length of the sigmoid colon is four times as long. The sigmoid vessels lie between the layers of the mesocolon.

Blood supply of the colon

The ascending colon and the proximal two-thirds of the transverse colon are supplied by the ileocolic, right colic and middle colic branches of the superior mesenteric artery, and the remainder of the colon by the left colic and sigmoid branches of the inferior mesenteric (p. 328). The anastomotic branches near the medial margin of

the whole colon form the 'arterial circle' commonly called (unofficially) the *marginal artery* and it is from this that short vessels run into the gut wall. The weakest link in this marginal chain of vessels is near the left colic flexure, between the middle and left colic branches, i.e. between midgut and hindgut vessels (and not, as was previously believed, between left colic and sigmoid branches).

The veins correspond to the arteries, and thus reach the portal vein via the superior or inferior mesenteric tributaries.

Lymph drainage

As is usual the lymph channels follow the blood vessels, so that drainage is to superior or inferior mesenteric nodes (p. 328).

Nerve supply

Being derived from the midgut (up to near the splenic flexure) and the hindgut (from there onwards), the parasympathetic supply to the large intestine is partly from the vagi and partly from the pelvic splanchnic nerves. The sympathetic supply is derived from spinal cord segments T10–L2. The pain fibres that accompany these vasoconstrictor nerves give rise to periumbilical pain if from midgut derivatives (e.g. the appendix) but to hypogastric pain if from the hindgut. As from the rectum, some pain fibres from the descending and sigmoid colon appear to run with the parasympathetic nerves (see also p. 380).

Colectomy

The vessel pattern with the accompanying lymphatics determines the extent of partial resections of the colon for carcinoma (Fig. 5.34). For a *right hemicolectomy* the resection extends from the terminal ileum to the proximal part of the transverse colon, with ligation of the ileocolic and right colic vessels adjacent to superior mesenteric parent. In a *transverse colectomy* the transverse colon and the right and left colic flexures are removed together with the transverse mesocolon and greater omentum and the middle colic vessels. For a *left hemicolectomy* the resection is from the left end of the transverse colon to part of the sigmoid colon, with ligation of left colic and sigmoid vessels, but the inferior mesenteric itself may have to be removed. For *sigmoid colectomy* the removal extends from the lower descending colon to the rectum. Resections for diverticular disease (as opposed to neoplasia) can of course be more localized.

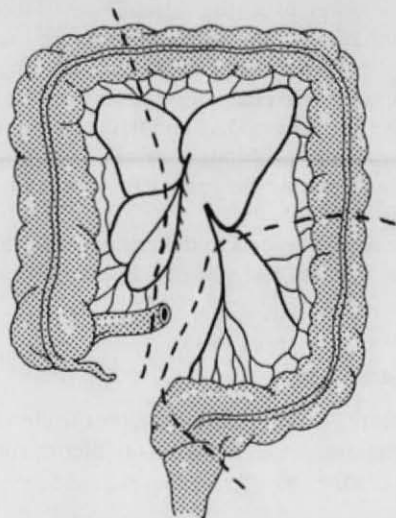


Fig. 5.34 Extent of large bowel resection for the two commonest partial colectomies: right hemicolectomy and sigmoid colectomy.

The **rectum** is considered with the pelvic organs on page 377, and the **anal canal** with the perineum on page 401.

PART 6 LIVER AND BILIARY TRACT

LIVER

The **liver**, the largest gland in the body, weighs 1500 g and receives 1500 ml of blood per minute. Its form has nothing to do with its function; the large wedge-shaped mass (Fig. 5.35) is merely a cast of the cavity into which it grows. It has two **surfaces**, diaphragmatic and visceral. The diaphragmatic surface is boldly convex, moulded to the under surface of the diaphragm, but is subdivided into anterior, superior, posterior and right surfaces which merge into one another without any clear demarcations, except where the sharp **inferior border** is formed. The visceral (or inferior) surface is rather flat and slopes downwards, forwards and to the right from the posterior surface, but again there is no clear dividing line. In the hardened dissecting room specimen this surface bears faint impressions from adjacent viscera. The junction of the visceral and anterior surfaces makes the sharp inferior border of the organ. Most main vessels and ducts enter or leave at the porta hepatis which is on the visceral surface, but the hepatic veins emerge from the posterior surface.

From the diaphragmatic and visceral surfaces peritoneal folds pass respectively across to the diaphragm and down to the stomach; these persist from the ventral mesogastrium into which the developing liver grows (Fig. 5.20).

The **diaphragmatic surface** is for the most part covered in peritoneum, which peels off in places to join the adjacent diaphragm. The anterior surface, viewed from the front (Fig. 5.35A), is triangular and related to the diaphragm, lungs and pleura (especially on the right), to ribs and costal cartilages 6–10 on the right, and to costal cartilages 6 and 7 on the left. Part of this surface lies behind the infracostal angle and is therefore covered by the anterior abdominal wall of the epigastrium. Above, the anterior surface curves backwards to become the *superior surface* which lies against the diaphragm with above it the pericardium and heart centrally and the pleura and lung on each side. The sharp lower border slopes up from right to left, first along the right costal margin and then across the epigastrium.

Over the anterior convexity the falciform ligament (p. 313) is attached from near the centre down to the notch made by the ligamentum teres in the lower border. This notch is to the left of the fundus of the gall bladder, which peeps below the inferior border. The upper attachment of the falciform ligament sweeps to the left along the upper surface of the liver as the left triangular ligament (Fig. 5.35A). It is a reduplication of the left leaf of the falciform ligament. The right leaf of the falciform ligament sweeps to the right, over the summit of the right dome, to pass just in front of the inferior vena cava and become the upper layer of the coronary ligament. It cannot be seen from the front (though present in Fig. 5.35A, a slightly superior view).

The *right surface* extends from ribs 7 to 11 and is related to the following logical sequence of structures: in its lower third to ribs and diaphragm; in its middle third to ribs, pleura and diaphragm; and in its upper third to ribs, pleura, lung and diaphragm.

The convexities of the superior and right surfaces continue into the *posterior surface* which lower down becomes the **visceral or inferior surface** (Figs 5.35B and 5.36). These latter two surfaces can be considered together when viewing the liver from behind (Fig. 5.35B). Their main feature is an H-shaped pattern of structures. Centrally lies the **porta hepatis** (the hilum of the liver), the cross-piece of the H. The right limb (incomplete) of the H is made by the inferior vena cava (on the posterior surface) and the gall bladder (inferior surface), while the left limb is made by the continuity of the fissures for the ligamentum venosum and ligamentum teres. The vena cava lies in a deep groove or sometimes a tunnel, on the convexity of

the posterior surface. To the right of the vena cava is the **bare area** which is in the shape of a triangle with the vena cava as its base and with sides formed by the *upper and lower layers of the coronary ligament*. The apex where these two layers meet is the *right triangular ligament*. The lower layer of the coronary ligament is attached along the blunt rounded border between the diaphragmatic and visceral surfaces. From here the single sheet of peritoneum sweeps down over the right kidney into the hepatorenal pouch and the right paracolic gutter (p. 316).

Trace the liver attachment of this inferior layer to the left, *in front of* the inferior vena cava, and thence up along its left side to the summit of the liver. Here it meets the right leaf that diverges from the falciform ligament (Fig. 5.35B). Together they are now traceable along the deep groove cut into the posterior surface by the ligamentum venosum (Fig. 5.36). These two layers

are short and are attached to the diaphragm. They enclose the caudate lobe in the upper recess of the lesser sac. The caudate lobe is the only part of the posterior surface that is in the lesser sac. It touches the diaphragm in front of the thoracic aorta, just to the left of the inferior vena cava and to the right of the oesophagus (Fig. 5.17). To the left of this the posterior surface tapers to its sharp extremity.

The fissure for the ligamentum venosum leaves the **visceral surface** and extends up to the posterior surface around the caudate lobe to meet the inferior vena cava, as already seen in the posterior view (Fig. 5.35B). The visceral surface is clothed in peritoneum which peels off as the lesser omentum.

The **porta hepatis** is the hilum of the liver and is enclosed between the two layers of the lesser omentum (Fig. 5.35B); from its left end these two layers are

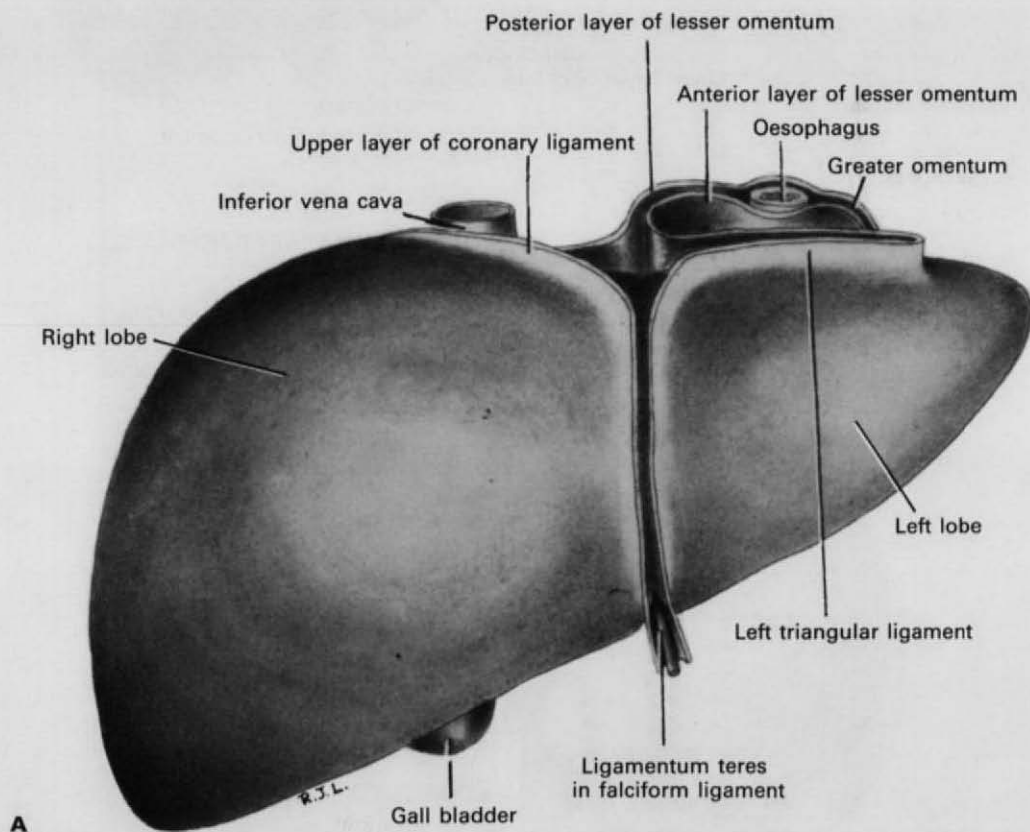


Fig. 5.35 Liver and peritoneal reflexions. **A** In the anterior view the oesophagus is pulled upwards from its normal position behind the left lobe to show the peritoneal attachments. All peritoneal edges seen here are attached to the diaphragm. **B** Posterior view (posterior and visceral surfaces). The lesser omentum, whose cut edges are seen in the fissure for the ligamentum venosum and which continues round the structures in the porta hepatis, is attached to the lesser curvature of the stomach. All other peritoneal edges seen here are attached to the diaphragm. The caudate process connects the caudate lobe to the right lobe.

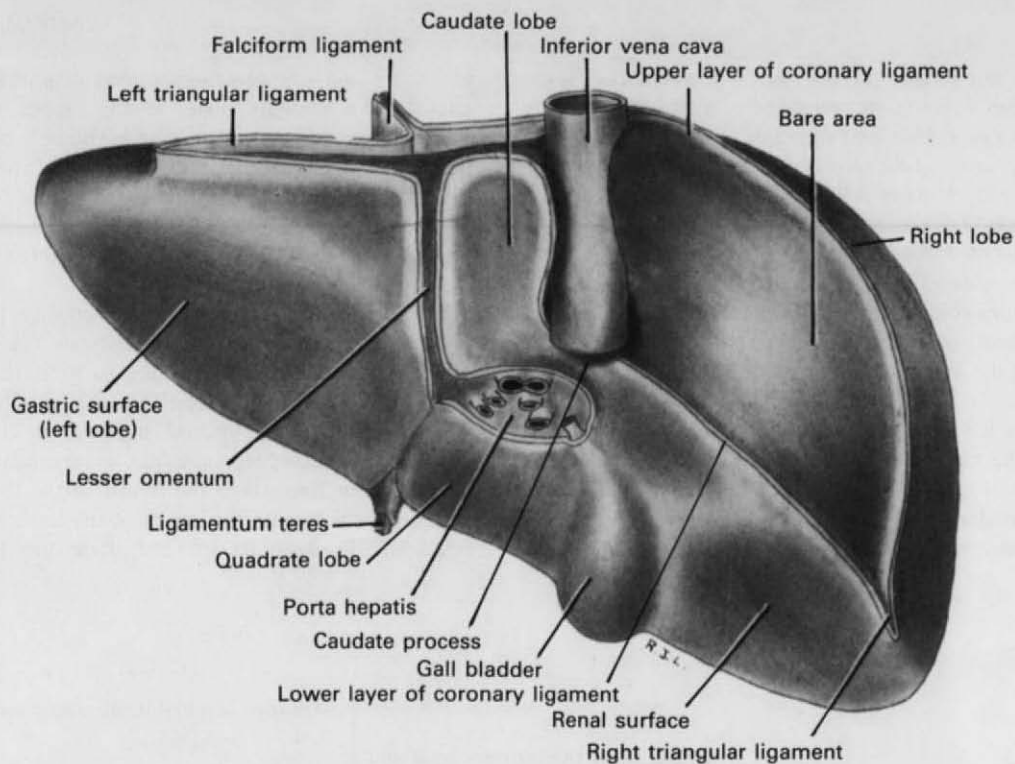


Fig. 5.35B

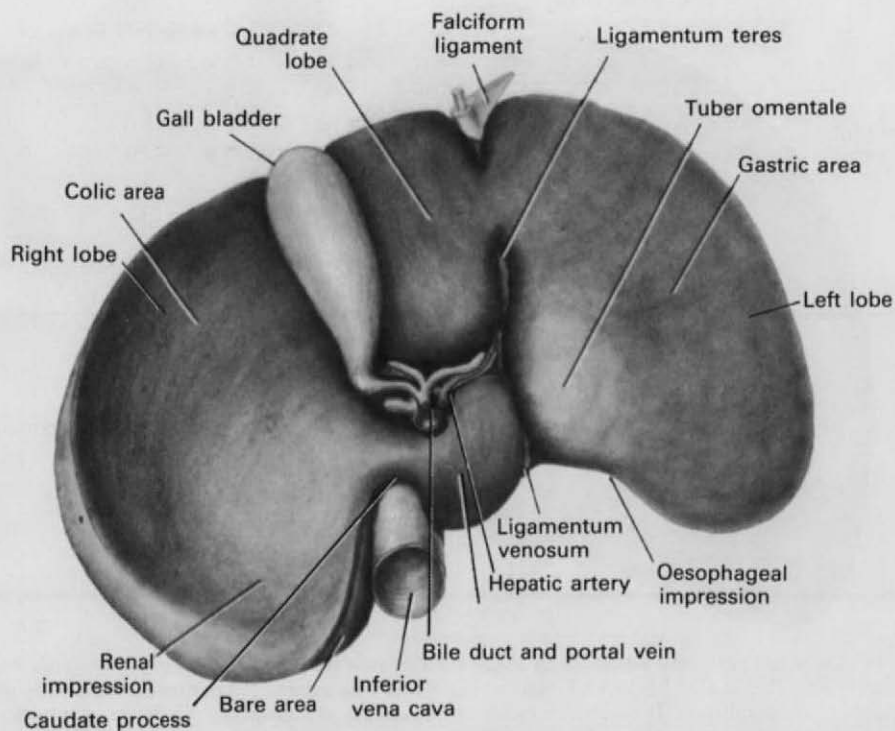


Fig. 5.36 Visceral surface of the liver, as seen when looking into the abdomen with the lower border of the liver lifted up towards the costal margin.

attached to the ligamentum venosum lying deep in its groove. The lesser omentum passes down from this liver attachment to enclose the stomach and the first 2.5 cm of the duodenum (p. 315). The porta is a transverse slit perforated by the right and left hepatic ducts and the right and left branches of the hepatic artery and portal vein. They lie in the order vein–artery–duct (VAD) with the ducts in front (more accessible in surgery).

The cystic duct lies in loose contact with the right end of the porta, and there are several lymph nodes here. These vessels, together with the nerves of the liver, lie enclosed between the layers of the free edge of the lesser omentum.

From the right end of the porta hepatis the gall bladder lies in a shallow fossa on the down-sloping visceral surface. Its neck is highest, its fundus lowest (see below).

The features considered to belong to the posterior surface (Fig. 5.35B) are the bare area and its bounding ligaments, part of the right suprarenal impression, the groove for the inferior vena cava, the caudate lobe and caudate process, the fissure for the ligamentum venosum, and impressions for the oesophagus and upper part of the stomach and possibly the tuber omentale of the pancreas (p. 353).

The features considered to belong to the visceral surface (Fig. 5.35B) are the porta hepatis and the lesser omentum extending into the fissure for the ligamentum venosum, impressions for parts of the right kidney and suprarenal gland, second part of the duodenum and right colic flexure, the gall bladder, the quadrate lobe, the fissure for the ligamentum teres and the rest of the gastric impression.

Stability

The normal or even the enlarged liver never falls down into the abdominal cavity. It is supported by the hepatic veins and the inferior vena cava. The hepatic veins (see below) are entirely intrahepatic and enter the vena cava while it is clasped in the deep groove on the posterior surface. At a postmortem examination the liver cannot be displaced caudally until the inferior vena cava is divided below the diaphragm. The thin inferior border of the liver is prevented from tilting downwards by the attachments of the left triangular ligament and the ligamentum teres and by resting on the underlying viscera (stomach and hepatic flexure of the colon).

Surface marking

Projected to the surface when viewed from the front, the upper margin of the liver is approximately level with the xiphisternal joint, arching slightly upwards on each

side. On the left it reaches the fifth intercostal space 7–8 cm from the midline, and on the right to the fifth rib, curving down to the right border which extends from ribs 7 to 11 in the midaxillary line. The inferior border is along a line joining the right lower and upper left extremities; some of it thus lies approximately level with the right costal margin, while centrally it crosses behind the upper abdominal wall between the costal margins.

Lobes

The lobes of the liver are left, caudate, quadrate and right (Fig. 5.35B). At the front and above, the falciform ligament divides the *anatomical left* and **right lobes**. At the back, the **caudate lobe** lies between the inferior vena cava and the fissure for the ligamentum venosum, and is connected to the right lobe (to the right of the inferior vena cava) by an isthmus of liver substance, the *caudate process*. The **quadrate lobe** lies between the gall bladder fossa and the fissure for the ligamentum teres. The old anatomists considered the caudate and quadrate lobes to be part of the right lobe, but it is of the utmost importance to appreciate that *functionally* the caudate lobe and most of the quadrate lobe belong to the *left* lobe; they receive their blood supply from the left branches of the hepatic artery and portal vein and deliver their bile to the left hepatic duct. The old anatomists knew that the right and left hepatic ducts are of equal diameter, as are the right and left branches of the hepatic artery and portal vein, but they failed to understand the functional division into two equal *halves*. The division runs along the plane of the gall bladder and the inferior vena cava.

Segments

On the basis of blood supply and biliary drainage (see below), there are four main anatomical segments: left lateral and left medial, right anterior and right posterior. The **left lateral segment** corresponds to the left anatomical lobe, and the **left medial segment** to the caudate and most of the quadrate lobe, with the line of the fissures for the ligamentum venosum and ligamentum teres demarcating these segments from one another. The line of demarcation of the functional right lobe from the rest of the liver is along the vena caval groove and the gall bladder fossa at the back, but at the front there is no visible landmark; the plane of division lies well to the right of the falciform ligament. The **right anterior** and **posterior segments** again have no

visible external marking, but the line of division runs obliquely and medially from the middle of the front of the right lobe towards the vena caval groove.

Liver experts now tend to refer to the above anatomical segments as *sectors*, and use the word *segment* for the subdivisions of these sectors based on the pattern of blood vessels divisions (which can be confirmed by modern scanning methods). A system using Roman numerals I–VIII is commonly adopted (Fig. 5.37). Segment I is the caudate lobe at the back. Segment II corresponds to the left lateral sector, and segments III and IV to lateral and medial parts of the left medial sector. Segments V and VIII are the lower and upper parts of the right anterior sector, and segments VI and VII are the lower and upper parts of the right posterior sector. Further details can be found in specialist texts.

Blood supply

The liver receives blood from two sources. Arterial (oxygenated) blood is furnished by the **hepatic artery** (p. 324), which divides into right and left branches in the porta hepatis. The division is Y-shaped, in contrast to the T-shaped division of the right and left branches of the portal vein. The right branch of the hepatic artery normally passes behind the common hepatic duct and in the liver divides into anterior and posterior segmental branches; the left branch divides into medial and lateral segmental branches. Sometimes the common hepatic artery arises from the superior mesenteric artery or the aorta (instead of the coeliac trunk), in which case it usually runs *behind* the portal vein. The right and left hepatic branches may themselves arise from the superior mesenteric or left gastric arteries respectively, constituting the aberrant hepatic arteries. They may

either *replace* the normal branches or exist *in addition* to them; the commonest is a left hepatic artery arising from the left gastric (in over 20% of bodies).

Venous blood is carried to the liver by the **portal vein** (p. 351) which divides in the porta hepatis into right and left branches which in turn give segmental branches like the arteries; this portal blood is laden with the products of digestion which have been absorbed from the alimentary canal, and which are metabolized by the liver cells.

The hepatic artery and portal vein are everywhere accompanied by tributaries of the hepatic ducts; the three together lie in 'portal canals' of histological sections. There is no communication between right and left halves of the liver; indeed, even within each half the arteries are end arteries (hence infarction of the liver). Although infarction may illustrate this point, in the presence of disease there are often enough anastomoses with phrenic vessels (e.g. across the bare area) to provide a collateral circulation that is sufficient to allow ligation of the hepatic artery, a procedure that has been used to induce metastases to regress without compromising normal liver tissue (though with less success than was hoped). From the portal canals the blood passes into the sinusoids between the rows of liver cells to the centre of each lobule. The arterial and portal venous blood become mixed in the sinusoids and then pass into the central vein in the centre of each lobule. The central veins of all the lobules unite to form the hepatic veins.

The venous return differs in that it shows a mixing of right and left halves of the liver. Three main **hepatic veins** (Fig. 5.37), high up near the diaphragmatic surface, drain into the inferior vena cava. A large central vein runs in the plane between right and left halves and receives from each. Further laterally lie a right and left vein; the middle vein frequently (60%) joins the left very near the vena cava. All the veins have no extrahepatic course and enter the vena cava just below the central tendon of the diaphragm. The entry of these large hepatic veins into the vena cava, already embedded in its deep groove of liver substance, is the main support for the liver (rather than the peritoneal ligaments). Several small accessory hepatic veins enter the vena cava below the main veins, including a separate vein from the caudate lobe.

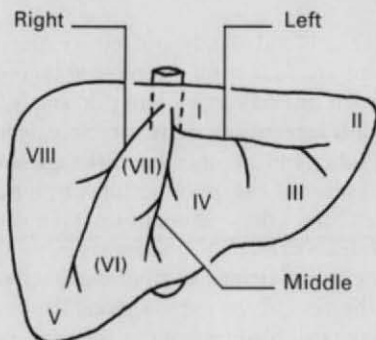


Fig. 5.37 Main hepatic veins and approximate positions of surgical segments, indicated by Roman numerals (posterior segments are in brackets). See text for explanation.

Lymph drainage

The lymphatics of the liver drain into three or four nodes that lie in the porta hepatis (*hepatic nodes*). These nodes also receive the lymphatics of the gall bladder. They drain downwards alongside the hepatic artery to

retropyloric nodes and so to the coeliac nodes. In some cases of carcinoma of the pylorus the retropyloric nodes become involved in spread of the disease, the afferent lymphatics become dilated, and *retrograde* spread of carcinoma may then involve the hepatic nodes. In such cases pressure of these nodes on a hepatic duct gives rise to obstructive jaundice. From the bare area the surface of the liver communicates with extraperitoneal lymphatics which perforate the diaphragm and drain to nodes in the posterior mediastinum. Similar communications exist along the left triangular and falciform ligaments from the adjacent liver surfaces.

Nerve supply

The nerve supply of the liver is derived from both the sympathetic and vagus, the former by way of the coeliac ganglia, whence nerves run with the vessels in the free edge of the lesser omentum and enter the porta hepatis. Vagal fibres from the left vagal trunk reach the porta hepatis along the lesser curve of the stomach via the lesser omentum.

Structure

The classic description of liver morphology is centred on the liver **lobule**, a region of liver tissue of something like pinhead size and hexagonal shape, with a central vein as the central feature, and with sinusoids and plates or cords of hepatocytes radiating from it to the periphery of the lobule where there may be fine connective tissue septa separating it from adjacent lobules (though in the human liver the septa are poorly developed compared with those in many animals such as the pig, whose liver is frequently studied histologically to demonstrate the typical pattern). At the 'corners' of the lobules small branches of the hepatic artery and portal vein are gathered with bile ductules, forming the *portal canals*. The vascular and biliary channels of the portal canals are united by anastomosing connexions which, although not obvious on histological sections, are fundamental to the concept of the functional unit of the liver being the 'acinus' rather than the lobule. The **acinus** on section is a diamond-shaped area with central veins at one pair of opposite corners and portal canals at the other pair, i.e. the acinus consists of parts of two adjacent lobules. The functional implication is that the hepatocytes of the region between the canals are the first to come under the influence of the incoming blood supply, whereas those nearest the central veins are the last to do so.

The **sinusoids** intervening between the cords of hepatocytes are lined (like all vessels) by endothelial cells which show frequent intercellular spaces and fenestrations.

These allow plasma (but not blood cells) to leave the sinusoids and enter the *perisinusoidal spaces* between the endothelium and hepatocytes, so that exchange of materials can take place between plasma and liver cells. Thus, contrary to common belief, the hepatocytes are not bathed in whole blood but only in plasma. Many of the endothelial lining cells are capable of phagocytic activity, constituting the *Kupffer cells* of the reticuloendothelial system. Bile manufactured by hepatocytes first enters the biliary canaliculi which are situated between apposing sides of adjacent hepatocytes. Collectively the canaliculi form a meshwork which drains into the bile ductules of the portal canals, and these in turn unite to form the larger intrahepatic ducts.

Development

The liver develops by proliferation of cells from the blind ends of a Y-shaped diverticulum which grows from the foregut into the septum transversum. The cranial part of the septum transversum becomes the pericardium and diaphragm. The caudal part becomes the ventral mesogastrium (Fig. 5.20), and it is into this that the liver grows (p. 322). At this stage the caudal part of the septum transversum transmits the vitelline veins which, by numerous anastomoses, form a rich venous plexus here. The proliferating liver cells break into branching buds of hepatocytes that form an anastomosing network whose meshes become filled with sinusoidal venous channels draining to the vitelline veins.

The original diverticulum from the endoderm of the foregut (Fig. 5.40A) becomes the bile duct; its Y-shaped bifurcation produces the right and left hepatic ducts. A blind diverticulum from the bile duct becomes the cystic duct and gall bladder (Fig. 5.40B). The hepatic ducts divide and redivide to become the interlobular and intralobular bile ductules. Hepatic circulation in the fetus is referred to on page 46.

Biopsy, lobectomy and transplantation

Needle **biopsy** of the liver is carried out through the right eighth or ninth intercostal space in the midaxillary line; the needle path is below the level of the lung but traverses the costodiaphragmatic recess of the pleura before going through the diaphragm and crossing the peritoneal cavity to enter the liver. The needle must not penetrate more than 6 cm from the skin to avoid entering the inferior vena cava. A misplaced needle could damage the kidney, colon or pancreas, and pneumothorax is another possible complication.

A **right hepatic lobectomy** involves removing liver tissue along a line from the left of the gall bladder to the right edge of the inferior vena cava, ligating vessels and

ducts along the way so that the right lobe and the gall bladder can be removed. For **left lobectomy**, the left lobe together with most of the caudate and quadrate lobes are removed. The gall bladder is left intact, and the line of resection at the back is level with the left edge of the vena cava. In left lobectomy it is important to preserve the right hepatic vein and vice versa. More precise removal of segments can be carried out based on their detailed vascular patterns.

In liver **transplantation** following removal of the patient's liver, the suprahepatic inferior vena cava of the donor liver is sutured to the patient's (but remains clamped), followed by reunion of the portal veins with restoration of circulation so that blood flows out of the lower end of the donor vena cava before joining it to the patient's infrahepatic vena cava. The suprahepatic vena cava is then unclamped, and the respective hepatic arteries and bile ducts joined up. Portal blood must flow through the liver to flush out accumulated potassium ions which are a potential cause of cardiac arrest; this is why the superior vena cava is kept clamped until the portal circulation has been restored. The viability of the bile duct is an important factor for a successful transplant; the cut end of the donor duct should bleed when the hepatic circulation is restored.

BILIARY TRACT

The extrahepatic biliary tract consists of the three hepatic ducts (right, left and common), the gall bladder and cystic duct, and the bile duct. Bile is manufactured by the liver cells. It is collected in bile canaliculi in the lobules, flows along the portal canals in the bile duct tributaries and so reaches the *right and left hepatic ducts*, which emerge at the porta hepatis. Here they join, and the *common hepatic duct* so formed passes down between the two peritoneal layers at the free edge of the lesser omentum. The common hepatic duct is soon joined by the cystic duct from the gall bladder, to form the bile duct (Fig. 5.38A). When retracted at operation the ducts descend below the liver, but at rest they lie in loose contact with the porta hepatis.

The development of the biliary tract is covered with that of the liver (above) and pancreas (p. 354).

Gall bladder

The gall bladder stores and concentrates the bile secreted by the liver. It is a globular or pear-shaped viscus (Figs 5.35B and 5.36) with a capacity of about 50 ml, and consists of three parts — fundus, body and neck. It lies in the gall bladder fossa on the visceral surface of the right lobe of the liver, adjacent to the

quadrate lobe. The liver is thus its main anterior relation. Its other important clinical relations are the anterior abdominal wall, duodenum and transverse colon.

Its bulbous blind end, the **fundus**, projects a little beyond the sharp lower border of the liver and touches the parietal peritoneum of the anterior abdominal wall at the tip of the ninth costal cartilage, where the transpyloric plane crosses the right costal margin, at the lateral border of the right rectus sheath (Fig. 5.1). This is the *surface marking* for the fundus and the area of abdominal tenderness in gall bladder disease. (The fundus of the normal gall bladder is not palpable but may become so if distended by biliary tract obstruction.) The fundus lies on the commencement of the transverse colon, just to the left of the hepatic flexure. The **body** passes backwards and upwards towards the right end of the porta hepatis and is in contact with the first part of the duodenum (hence the staining of the duodenum by bile in dissecting room specimens). The upper end of the body narrows into the **neck** which, when the liver is in its normal position (not retracted upwards), lies at a higher level than the fundus and against the free edge of the lesser omentum. The neck continues into the **cystic duct**, which is 2–3 cm long and 2–3 mm in diameter. It runs towards the porta to join the common hepatic duct (so forming the bile duct) between the two layers of peritoneum that form the free edge of the lesser omentum (Fig. 5.38A) about 1 cm above the duodenum and usually in front of the right hepatic artery and its cystic branch (but variations are common — see Bile duct, below). The wall of the neck where it joins the cystic duct may show a small diverticulum (Hartmann's pouch) which may become the site of impaction of a gallstone. However, this is not a feature of the normal gall bladder and is always associated with a pathological condition.

The fundus and body of the gall bladder are firmly bound to the under surface of the liver by connective tissue and many small cystic veins that pass from the gall bladder into the liver substance. The peritoneum covering the liver passes smoothly over the gall bladder. Occasionally the gall bladder hangs free on a narrow 'mesentery' from the under surface of the liver, a condition that greatly facilitates cholecystectomy.

Blood supply

The gall bladder receives many small vessels from its hepatic bed, but there is also a cystic artery (Fig. 5.38A), usually a branch of the right hepatic. It passes behind the cystic duct to reach the neck of the gall bladder and then branches out over the surface of the viscus. The artery should be found running towards

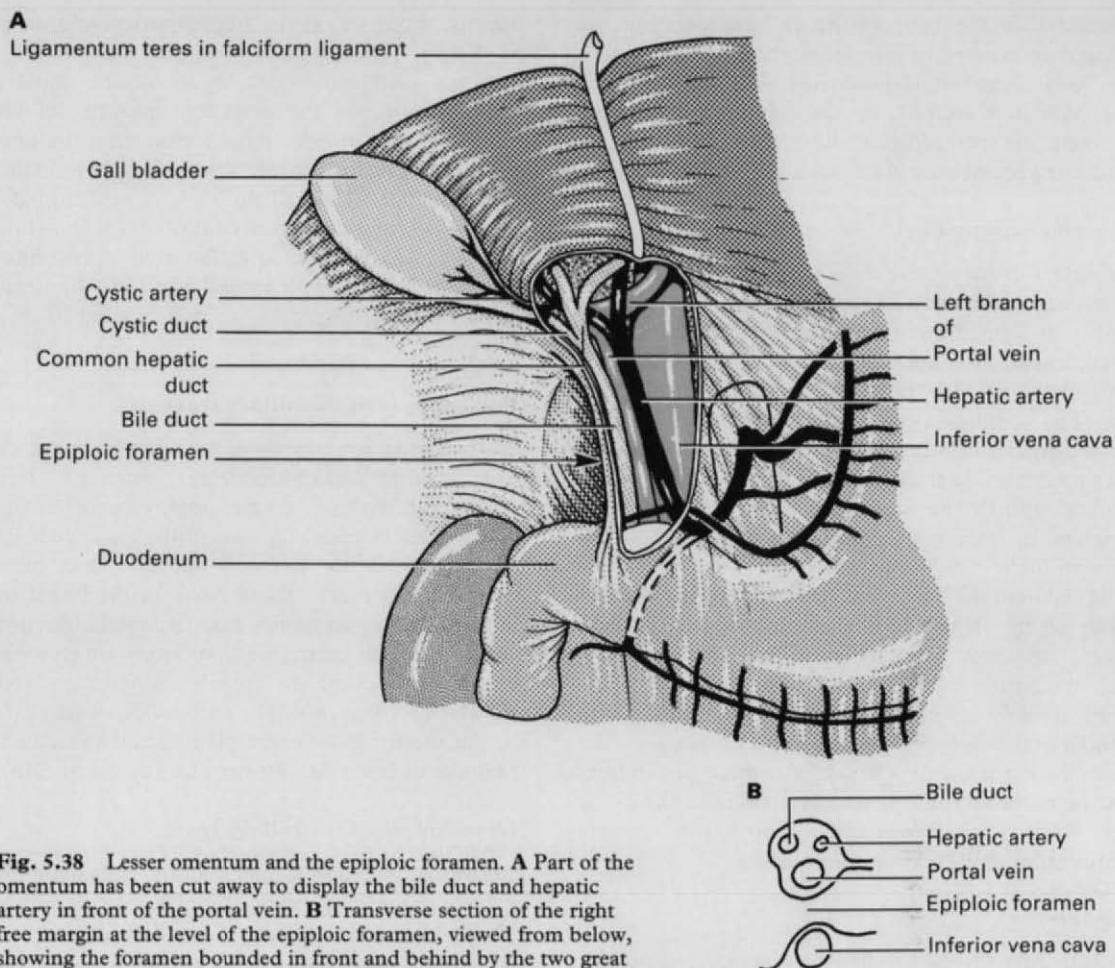


Fig. 5.38 Lesser omentum and the epiploic foramen. **A** Part of the omentum has been cut away to display the bile duct and hepatic artery in front of the portal vein. **B** Transverse section of the right free margin at the level of the epiploic foramen, viewed from below, showing the foramen bounded in front and behind by the two great veins.

the gall bladder in the triangle formed by the liver, common hepatic duct and cystic duct (*Calot's triangle*), but variations in the origin of the artery are common. It may arise from the main trunk of the hepatic artery, from the left branch of that vessel or from the gastroduodenal artery, and in either case may pass in front of the cystic and bile ducts. Thrombosis of the cystic artery does not usually lead to ischaemia of the gall bladder because the supply from the gall bladder bed is adequate (in contrast to the appendix, whose supply is by an end artery, p. 339).

Venous return is by multiple small veins in the gall bladder bed into the substance of the liver and so into the hepatic veins. One or more cystic veins may be present but these are uncommon; they run from the neck of the gall bladder into the right branch of the portal vein. Note that cystic veins do not accompany the cystic artery.

Lymph drainage

Lymphatic channels from the gall bladder drain to nodes in the porta hepatis, to the cystic node (in Calot's triangle at the junction of the common hepatic and cystic ducts), and to a node situated at the anterior border of the epiploic foramen. From these nodes lymph passes in the free edge of the lesser omentum to the coeliac group of preaortic nodes.

Structure

The gall bladder is a fibromuscular sac which, histologically, shows a surprisingly small amount of smooth muscle in its wall. Its mucous membrane is a lax areolar tissue lined with a simple columnar epithelium. It is projected into folds which produce a honeycomb

appearance in the body of the gall bladder, but are arranged in a more or less spiral manner in the neck (the '*spiral valve*' of Heister) just short of the cystic duct. Mucus is secreted by the columnar epithelium but there are no goblet cells, and mucus-secreting glands are present only in the neck.

Common hepatic duct

The *right* and *left hepatic ducts* emerge from the porta hepatis and unite near its right margin in a Y-shaped manner to form the **common hepatic duct**. This is joined, usually after about 3 cm (but in Fig. 5.38A it is unusually short), by the cystic duct to form the bile duct. The common hepatic duct is about 4 cm long with a diameter of 4 mm; it lies in the free edge of the lesser omentum, in front of the right edge of the portal vein and with the hepatic artery on its left. The right branch of the hepatic artery normally passes behind the common hepatic duct but may run in front of it. The site of union of the cystic and common hepatic ducts is usually on the right side of the common hepatic duct about 1 cm above the duodenum, but sometimes the cystic duct runs parallel to and on the right of the hepatic duct for a variable distance before uniting with it, and it may also spiral round behind the hepatic duct before joining it on its left side. All these possibilities must be borne in mind when dissecting out the cystic duct during cholecystectomy; obviously correct identification of the various ducts is vital.

Bile duct

The **bile duct** (formerly called the common bile duct) is about 8 cm long and 8 mm in diameter, and is best described in three parts or thirds. The upper (supraduodenal) third lies in the free edge of the lesser omentum (Fig. 5.38) in the most accessible position for surgery — in front of the portal vein and to the right of the hepatic artery, where the lesser omentum forms the anterior boundary of the epiploic foramen. Here it may be incised (choledochotomy) for removal of a stone or insertion of a drainage tube. The middle (retroduodenal) third (Figs 5.29 and 5.41D) runs behind the first part of the duodenum and slopes down to the right, away from the almost vertical portal vein which now lies to the left of the duct with the gastroduodenal artery. The inferior vena cava is behind the duct. The lower (paraduodenal) third slopes further to the right in the groove between the back of the head of the pancreas and the second part of the duodenum (it may even be embedded in a tunnel of pancreatic tissue) and in front of the right renal vein. Neoplasms of the head of the pancreas may obstruct the duct here. It joins the pancreatic duct (Fig. 5.41D) at an

angle of about 60° at the **hepatopancreatic ampulla** (of Vater). The ampulla and the ends of the two ducts are each surrounded by sphincteric muscle, the whole constituting the *ampullary sphincter* (of Oddi). Sometimes the muscle fibres surrounding the ampulla and the pancreatic duct are absent, leaving only the bile duct sphincter. When all three are present the arrangement allows for independent control of flow from bile and pancreatic ducts. The ampulla itself opens into the posteromedial wall of the second part of the duodenum at the major duodenal papilla, which is situated 10 cm from the pylorus.

Blood supply of the biliary tract

The bile duct receives small branches from the cystic, hepatic and gastroduodenal arteries, forming anastomotic channels on the duct, especially along its right and left borders. Ligation of the cystic duct should not be carried out too near the bile duct to avoid compromising these vessels. Most of the blood to the supraduodenal part comes from below. Lower down a branch from the gastroduodenal artery which joins the posterior branch of the superior pancreaticoduodenal and which is often called the retroduodenal artery, forms a major supply. In liver transplantation the vascularity of the donor duct is a vital element for success (p. 348).

Nerve supply of the biliary tract

Parasympathetic fibres, mainly from the hepatic branch of the anterior vagal trunk, stimulate contraction of the gall bladder and relax the ampullary sphincter, and sympathetic fibres from cell bodies in the coeliac ganglia (with preganglionic cells in the lateral horn of spinal cord segments T7–9) inhibit contraction, but the hormonal control of gall bladder activity (by CCK from enteroendocrine cells of the upper small intestine) is much more important than the neural. Afferent fibres including those subserving pain (e.g. from a duct distended by a gallstone) mostly run with right-sided sympathetic fibres and reach spinal cord segments T7–9, but some from the gall bladder may run in the right phrenic nerve (C3–5). Any afferent vagal fibres are probably concerned with reflex activities, not pain. Biliary tract pain is usually felt in the right hypochondrium and epigastrium, and may radiate round to the back in the infrascapular region, in the area of distribution of spinal nerves T7–9. The phrenic nerve supply explains the occasional referral of pain to the right shoulder region.

Surgical approach to the biliary tract

The fundus of the gall bladder should be easy to see

after opening the abdomen (e.g. through a Kocher's incision below the right costal margin) but to display the rest of it and the duct system the adjacent liver, transverse colon and duodenum must be suitably retracted and the peritoneum over the cystic duct and the upper end of the free margin of the lesser omentum incised. The various ducts and vessels are dissected out and all must be positively identified, taking special care not to confuse the cystic duct with the bile duct. For *cholecystectomy* the cystic duct and artery are ligated and the gall bladder dissected away from the hepatic bed from the neck towards the fundus. For *operative cholangiography* the cannula is inserted into the cystic duct and passed down into the bile duct; the spiral valve may cause some obstruction. The upper end of the bile duct can be incised longitudinally (*choledochotomy*) for the removal of stones. The lower part of the duct can be exposed by mobilization of the duodenum (*Kocher's manoeuvre*), incising the peritoneum along the right edge of the second part of the duodenum and turning the duodenum medially so that the posterior surface of the duodenum and head of the pancreas with the duct between them can be palpated and seen. The inferior vena cava, ureter and gonadal vessels must not be damaged when peeling the duodenum forwards.

PORTAL VEIN

The **portal vein** is the upward continuation of the superior mesenteric vein, which changes its name to portal after it has received the splenic vein behind the neck of the pancreas. It lies in front of the inferior vena cava, passes upwards behind the pancreas and the first part of the duodenum and loses contact with the inferior vena cava by entering between the two layers of the lesser omentum. It runs almost vertically upwards in the free edge, where the lesser omentum forms the anterior boundary of the epiploic foramen, lying behind the bile duct and the hepatic artery (Fig. 5.38), and reaches the porta hepatis. Here it divides in a T-shaped manner into a right and left branch which enter the respective halves of the liver. Below the first part of the duodenum the bile duct and hepatic artery are curved away from it; the bile duct curves to the right *behind the pancreas* and the hepatic artery curves to the left *in front of the pancreas* to the coeliac trunk.

The portal vein normally receives as tributaries the superior mesenteric and splenic veins (which form it), the right and left gastric veins (and therefore blood from the lower end of the oesophagus as well as the stomach), and the superior pancreaticoduodenal veins. In addition, the cystic vein or veins join the right branch of the portal vein, and the periumbilical veins running with the

ligamentum teres join the left branch. The ligamentum itself (the obliterated remains of the left umbilical vein) is often not completely fibrosed even in adults (50%), and it can be cannulated at the umbilicus.

With blood coming into the portal vein mainly in two streams (superior mesenteric and splenic) it might be expected that mesenteric blood might pass mainly to the right lobe and splenic blood to the left. Although in animals the site of some liver diseases can be explained by such streaming of blood, pathological studies show that there is no significant streaming in the human liver.

The five sites of portal/systemic anastomosis are considered with the appropriate territories: lower end of the oesophagus (p. 278), upper end of the anal canal (p. 403), bare area of the liver (p. 346), periumbilical region (p. 241) and retroperitoneal areas (p. 340).

In *portal hypertension* 80% of portal blood is shunted into the collateral channels so that only 20% reaches the liver; the opening up of the collaterals does not decrease the level of hypertension.

Development

Below the liver right and left vitelline veins (p. 45) are joined by channels both ventral and dorsal to the duodenum (Fig. 5.39A). The splenic and superior mesenteric veins drain to the left vitelline vein, whose cranial end disappears (Fig. 5.39B), leaving the dorsal cross-channel to become the lower part of the portal vein. The upper part of the right vitelline vein and the ventral cross-channel persist as the upper part of the portal vein (Fig. 5.39B and C). The cranial ends of the vitelline veins become hepatic veins, and the uppermost part of the right vitelline vein becomes the uppermost part of the inferior vena cava.

PART 7 PANCREAS

The **pancreas** is a composite gland whose exocrine acini discharge their secretions into the duodenum to assist in digestion, and with groups of endocrine cells, the islets of Langerhans, whose special role is in carbohydrate metabolism. In shape the gland resembles the upper end of a thick walking-stick or hook, lying sideways with the handle or hook on the right and turned downwards, and with a length of about 15 cm (Fig. 5.29).

The gland is of firm consistency, and its surface is finely lobulated. It is retort-shaped, tapering from a big head to a narrow tail.

The pancreas lies immediately behind the

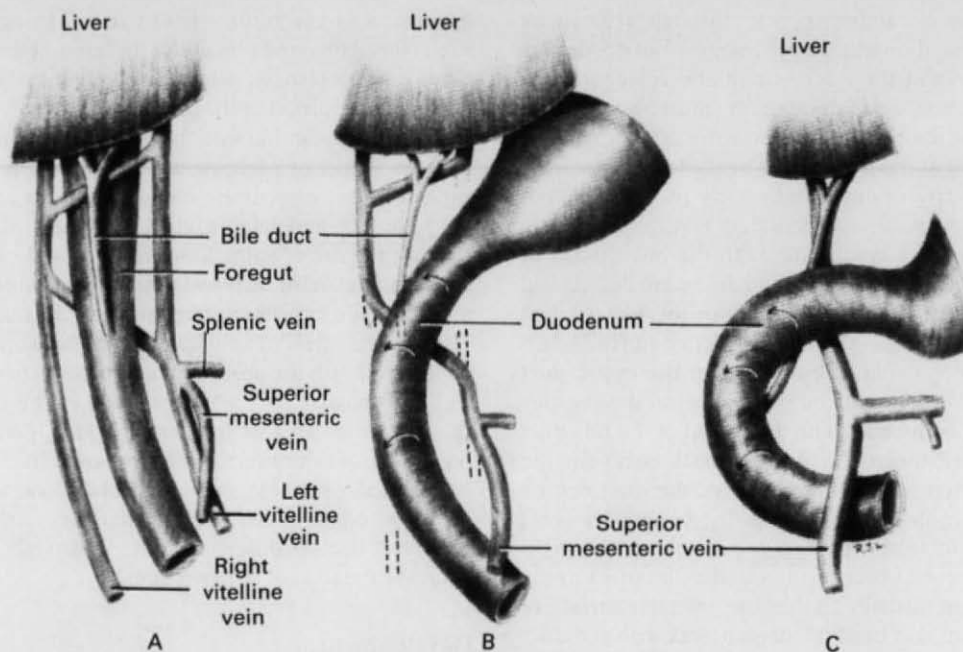


Fig. 5.39 Development of the portal vein and the rotation of the duodenum. In **A**, the right and left vitelline veins, running alongside the duodenum, communicate by anastomosing cross-channels. In **B**, the cross-channels persist, with the dotted outlines indicating the disappearing parts of the vitelline veins. The elongating duodenum is rotating, carrying the entrance of the bile duct round to the dorsal aspect. In **C**, the final stage is shown, with the bile duct entering the posteromedial surface of the duodenum.

peritoneum of the posterior abdominal wall. The transverse mesocolon is attached to its anterior surface just above the inferior border; thus most of the gland lies in the supracolic compartment (in the lesser sac, forming part of the stomach bed), but a narrow strip along its inferior border lies in the infracolic compartment. It consists of head, neck, body and tail. The head and tail incline towards the paravertebral gutters, while the neck and body are curved boldly forward over the inferior vena cava and aorta in front of the first lumbar vertebra. The gland lies somewhat obliquely, sloping from the head upwards towards the tail. The transpyloric plane (L1) is the guide to the *surface marking*.

The **head**, the broadest part of the pancreas, is moulded to the C-shaped concavity of the duodenum, which it completely fills. It lies over the inferior vena cava and the right and left renal veins at the level of L2 vertebra. Its posterior surface is deeply indented, and sometimes tunnelled, by the terminal part of the bile duct. The lower part of the posterior surface is prolonged, wedge-shaped to the left, behind the superior mesenteric vein and artery, in front of the aorta; this is the **uncinate process** of the head. The anterior surface of the head lies in both supracolic and infracolic

compartments; some of this surface is bare, for the leaves of the greater omentum and of the transverse mesocolon are here wide apart at their attachments (Fig. 5.17).

The **neck** is best defined as the narrow band of pancreatic tissue that lies in front of the superior mesenteric and portal veins, continuous to the right with the head and to the left with the body. At the lower margin of the neck the superior mesenteric vein is embraced between the neck and the uncinate process of the head, and the splenic vein runs into the left side of the vertical superior mesenteric-portal channel. The transverse mesocolon is attached towards the lower border of the neck, which lies in the stomach bed of the lesser sac (omental bursa).

The **body** of the pancreas passes from the neck to the left, sloping gently upwards across the left renal vein and aorta, left crus of the diaphragm, left psoas muscle and lower pole of the left suprarenal gland, to the hilum of the left kidney. Its upper border crosses the aorta at the origin of the coeliac trunk; the splenic artery passes to the left along the upper border of the body and tail, the crests of the waves showing above the pancreas, the troughs out of sight behind it (Fig. 5.29). Its lower border, alongside the neck, crosses the origin of the



Fig. 5.40 CT scan of the upper abdomen, viewed from below. 1: Gall bladder. 2: Liver. 3: Portal vein. 4: Inferior vena cava. 5: Pancreas. 6: Spleen. 7: Left kidney. 8: T12 vertebra. 9: Abdominal aorta. 10: Right crus of diaphragm. 11: Coeliac trunk.

superior mesenteric artery. Towards the right of the anterior surface there is a slight convexity, the tuber omentale. Above the lesser curvature of the stomach this touches the tuber omentale of the left lobe of the liver, with the lesser omentum intervening. Because the pancreas usually slopes slightly upwards, its whole length is not necessarily seen in one CT scan (Fig. 5.40). The splenic vein lies closely applied to its posterior surface; the inferior mesenteric vein joins the splenic vein behind the body of the pancreas in front of the left renal vein where it lies over the left psoas muscle. The transverse mesocolon is attached towards the lower part of the anterior surface; the body lies, therefore, behind the lesser sac, where it forms part of the stomach bed.

The **tail** of the pancreas passes forward from the anterior surface of the left kidney at the level of the hilum. Accompanied by the splenic artery, vein and lymphatics it lies within the two layers of the lienorenal ligament and thus touches the hilum of the spleen.

The **pancreatic duct** (of Wirsung) is a continuous tube leading from the tail to the head, gradually increasing in diameter as it receives delicate tributaries. At the hepatopancreatic ampulla (p. 350 and Fig. 5.41D) it is joined at an angle of about 60° by the bile duct; in intubation of the ampulla for endoscopic retrograde cholangiopancreatography (ERCP), the catheter preferentially enters the pancreatic duct. It drains most of the pancreas except for the uncinata process and

lower part of the head, which drains by the *accessory pancreatic duct* (of Santorini). For developmental reasons (see below) this opens into the duodenum at the minor duodenal papilla situated about 2 cm proximal to the major papilla. The two ducts frequently communicate with one another.

Blood supply

The main vessel is the splenic artery (p. 324), which supplies the neck, body and tail. One large branch is named the *arteria pancreatica magna*. The head is supplied by the *superior* and the *inferior pancreaticoduodenal arteries* (p. 325). Venous return is by numerous small veins into the splenic vein and, in the case of the head, by the superior pancreaticoduodenal vein into the portal vein and by the inferior pancreaticoduodenal vein into the superior mesenteric.

Lymph drainage

Lymphatics from the pancreas follow the course of the arteries. To the left of the neck the pancreas drains into the retropancreatic nodes. The head drains from its upper part into the coeliac group and from its lower part and uncinata process into the superior mesenteric group of preaortic lymph nodes.

Nerve supply

Parasympathetic vagal fibres, which are capable of stimulating exocrine secretion, reach the gland mainly from the posterior vagal trunk and coeliac plexus, but, as with the gall bladder, hormonal control is more important than the neural. Sympathetic vasoconstrictor impulses are derived from spinal cord segments T6–10 via splanchnic nerves and the coeliac plexus, the postganglionic fibres running to the gland with its blood vessels. As with other viscera, pain fibres accompany the sympathetic supply, so that pancreatic pain may radiate in the distribution of thoracic dermatomes 6–10.

Structure

The pancreas is a lobulated gland composed of serous acini that produce the exocrine secretion, and the endocrine islets of Langerhans. The cells of the serous acini are very like those of the salivary glands, showing the cytoplasmic basophilia typical of protein-secreting cells. Under the influence of secretin and CCK produced by enteroendocrine cells of the small intestine, the pancreatic acinar cells secrete various digestive

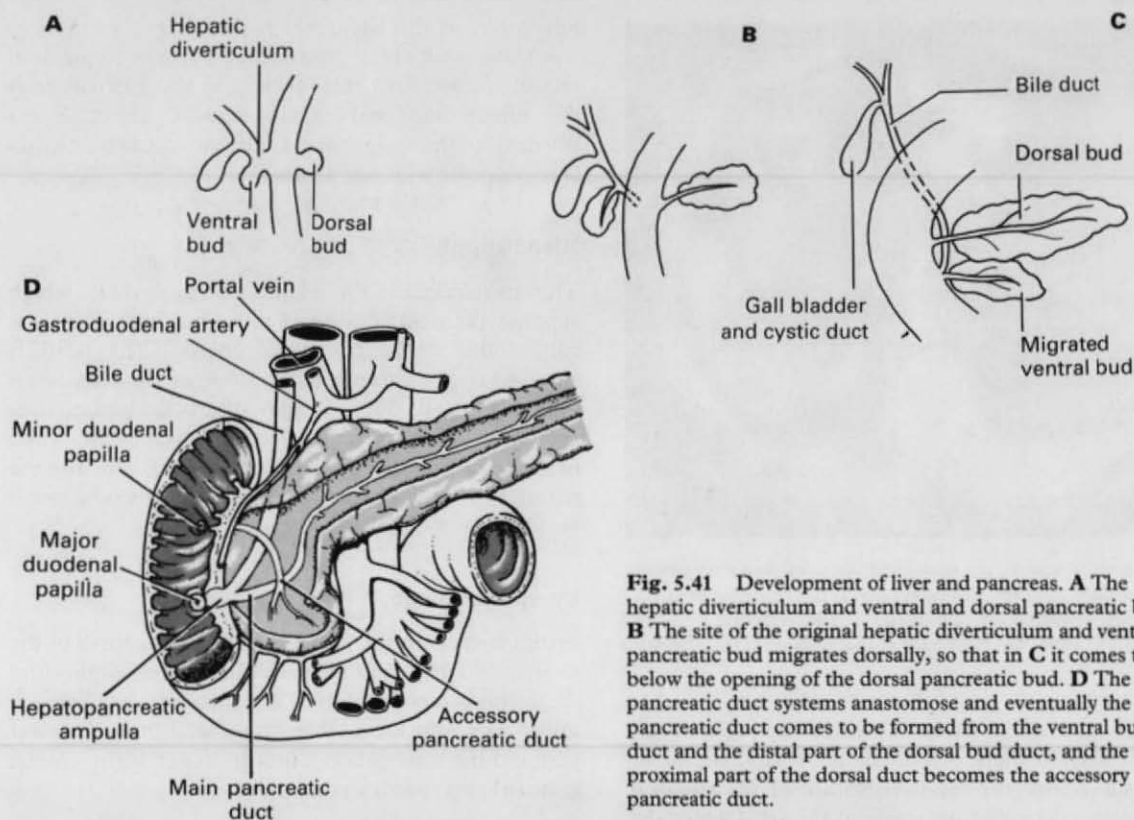


Fig. 5.41 Development of liver and pancreas. **A** The hepatic diverticulum and ventral and dorsal pancreatic buds. **B** The site of the original hepatic diverticulum and ventral pancreatic bud migrates dorsally, so that in **C** it comes to lie below the opening of the dorsal pancreatic bud. **D** The pancreatic duct systems anastomose and eventually the main pancreatic duct comes to be formed from the ventral bud duct and the distal part of the dorsal bud duct, and the proximal part of the dorsal duct becomes the accessory pancreatic duct.

enzymes, in particular trypsin and lipase, and some (the centroacinar cells) produce bicarbonate. Ducts appear to be scanty among the acini (compare with the parotid gland, where ducts are a prominent feature); the larger ones are found in the interlobular connective tissue. The pale-staining islets are rounded groups of cells scattered among the acini; the mixture of islets and acini is the characteristic microscopic feature of the pancreas. Special staining or electron microscopy is necessary to distinguish between the α -islet cells which secrete glucagon and the β -cells secreting insulin. There are also δ -cells that produce somatostatin.

Development

The pancreas develops as two separate buds, each an outgrowth of the endoderm at the junction of foregut and midgut (Fig. 5.41A). A *ventral bud* grows into the ventral mesogastrium in common with the outgrowth of the bile duct and a *dorsal bud* grows independently from a separate duct into the dorsal mesogastrium. The duodenal portion of the gut subsequently rotates (Fig. 5.39) and becomes adherent to the posterior abdominal wall. It, with the pancreatic outgrowths, finally lies behind the peritoneum. The duodenal wall

grows asymmetrically; the openings of the two ducts, originally diametrically opposite, are thus carried around into line with each other (Fig. 5.41B and C), and the two parts of the gland fuse into the single adult pancreas. The duct systems of the two buds anastomose and there is eventually some interchange of drainage areas. The end result is that the duodenal end of the dorsal duct becomes the accessory pancreatic duct, and the duct of the ventral bud joins with the remainder of the dorsal duct to form the main pancreatic duct (Fig. 5.41D).

The pancreatic acini develop by growth of cells from the terminal parts of the branching ducts. The islet cells appear to have an identical origin, but become separated from their parent ducts and undergo a complete change of secretory function.

Surgical approach

The head of the pancreas can be mobilized by Kocher's manoeuvre (p. 351). Transection of the stomach and reflexion of the cut ends to each side gives greater exposure of the pancreas. Resections of the head of the pancreas with the C-shaped duodenal loop involve restoring continuity by joining the bile duct to the end of the jejunum and the stomach and pancreas to the side of

it. Pseudocysts of the pancreas (fluid accumulations following pancreatitis) bulge into the lesser sac, usually behind the stomach, and can be drained intragastrically by incising the anterior wall of the stomach and then entering the cyst by incising the posterior gastric wall.

PART 8 SPLEEN

The **spleen**, the largest of the lymphoid organs (p. 16), lies under the diaphragm on the left side of the abdomen (Fig. 5.29), and although not part of the alimentary tract it drains to the portal venous system.

The odd numbers 1, 3, 5, 7, 9, 11 summarize certain statistical features of the spleen. It measures $1 \times 3 \times 5$ inches, weighs 7 oz and lies between the ninth and eleventh ribs (H. A. Harris). The spleen is a firm organ of a dull red colour, roughly (for those who dislike the above imperial measures) the size and shape of a clenched fist. The measurements quoted are average; the size of the spleen varies considerably.

Being developed in the dorsal mesogastrium (see below), the spleen projects into the greater sac surrounded by peritoneum of the original left leaf of the dorsal mesogastrium. It lies at the left margin of the lesser sac (Fig. 5.47) below the diaphragm, and its *diaphragmatic surface* is moulded into a reciprocal convexity. Its *hilum* lies in the angle between the stomach and left kidney, each of which impresses a concavity alongside the attached splenic vessels (Fig. 5.42). Its long axis lies along the line of the tenth rib, and its lower pole does not normally project any further forward than the midaxillary line. A small *colic area* lies in contact with the splenic flexure and the phrenicocolic ligament. Its anterior border is notched, a relic of the fusion of the several 'splenules' from which the organ arises in the embryo (see below).

Its visceral peritoneum, or serous coat, invests all surfaces (gastric, diaphragmatic, colic and renal) and at the hilum comes into contact with the right leaf of the greater omentum. The two leaves of the greater omentum, now in contact, pass from the hilum forwards to the greater curvature of the stomach (the gastrosplenic ligament) and backwards to the front of the left kidney (the lienorenal ligament) (Fig. 5.47). The peritoneal attachment at the hilum of the spleen extends down towards the lower pole, and this attachment makes a ridge in the greater omentum. This attachment can easily be torn, accidentally, during splenectomy. The hilum of the spleen makes contact with the tail of the pancreas, which lies within the lienorenal ligament (Fig. 5.47).

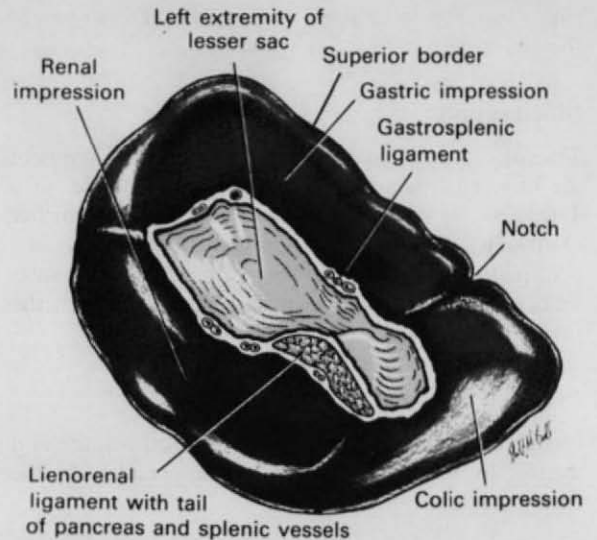


Fig. 5.42 Visceral surface of the spleen, showing the impressions for adjacent viscera and the two layers of peritoneum that form the lienorenal and gastrosplenic ligaments.

If the spleen enlarges, its long axis extends down and forwards along the tenth rib in the direction of the umbilicus, and its anterior border approaches the costal margin to the left of the greater curvature of the stomach. (A kidney enlarging downwards does so in the direction of the iliac fossa.) The spleen must at least double its normal size before its anterior border passes beyond the left costal margin. A palpable spleen is identified by the notch in its anterior border. In some diseases the spleen is grossly enlarged, and may extend across the upper abdomen to far beyond the umbilicus. Whatever the degree of enlargement the spleen glides in contact with the diaphragm and anterior abdominal wall in front of the splenic flexure, which remains anchored to the lower pole of the left kidney, and no colonic resonance is found on percussion over the organ. Retroperitoneal tumours (e.g. of the left kidney) do not displace the overlying colon and they are crossed by a band of colonic resonance, a further diagnostic point.

To identify the surfaces of the detached spleen hold the convexity of the organ (its diaphragmatic surface) in the hollow of the left hand. Rotate it until the notched anterior border lies to the front, near the thumb (Fig. 5.42). The concavity behind the notched anterior border is the gastric impression; it leads back to the low prominence of the hilum. Behind the hilum is the concave renal surface, while at the lower pole (at the tip of the little finger of the left hand) is the small colic impression.

The *structure* of the spleen has been referred to on

page 16. For accessory spleens, see Development (below).

Blood supply

The splenic artery (p. 324) passes between the layers of the lienorenal ligament and at the hilum divides in a T-shaped or Y-shaped manner. Usually further branching gives rise to four segments (perhaps only two or three); intersegmental vessels are small and scanty. Veins accompany the arteries and unite to form the splenic vein (p. 325).

Lymph drainage

Lymph drains into several nodes lying at the hilum and thence, by way of the retropancreatic nodes, to the coeliac nodes.

Nerve supply

The spleen is supplied from the coeliac plexus with sympathetic fibres only.

Development

The spleen begins to develop in the sixth week as several condensations of mesodermal cells in the dorsal mesogastrium which, because of the splenic presence, becomes divided into the lienorenal and gastrosplenic ligaments (Fig. 5.24B and p. 323). The spleen thus comes to lie at the left margin of the lesser sac. The original condensations become aggregated into a single organ; the splenic notch may represent a region where there is a lack of fusion. 'Accessory spleens' are the result of lack of fusion; one or several may be found, usually along the splenic vessels or in the peritoneal attachments. They are commoner than is usually realized (1 in 10 individuals).

Surgical approach

Removal of the spleen (**splenectomy**) essentially involves cutting its two 'pedicles', the lienorenal and gastrosplenic ligaments. In an emergency after rupture with haemorrhage, the left or posterior layer of the lienorenal ligament is incised and the spleen turned medially so that the splenic vessels can be dissected away from the tail of the pancreas and ligated (arteries before veins). The short gastric vessels and the gastrosplenic ligament are then divided and removal completed. For an elective procedure it is usual to enter the lesser sac by dividing the gastrosplenic ligament and its vessels and then to deal with the splenic vessels and the lienorenal ligament. The

stomach must not be perforated when ligating the short gastric vessels and damage to the tail of the pancreas and splenic flexure of the colon must be avoided.

PART 9

POSTERIOR ABDOMINAL WALL

The five lumbar vertebrae project forwards into the abdominal cavity; the lumbar spine has a normal lordosis (forward convexity). The midline forward projection is enhanced by the inferior vena cava and aorta, which lie in front of the bodies of the vertebrae (Fig. 5.43A). To each side of this convexity lie deep paravertebral gutters. They are floored in by the psoas and quadratus lumborum muscles and, below the iliac crest, by the iliocostalis muscle. The crura and adjacent parts of the diaphragm (p. 249) are really also part of the posterior abdominal wall. The kidneys lie high up in the paravertebral gutters.

The lumbar vertebrae are separated from each other by thick intervertebral discs, which unite them very strongly. A broad ribbon, the anterior longitudinal ligament, is attached anteriorly and crosses the lumbosacral prominence to become fused with the periosteum in the hollow of the sacrum.

MUSCLES

Psoas major

This muscle lies in the gutter between the bodies and transverse processes of the lumbar vertebrae. Its vertebral attachment is to the *discs above the five lumbar vertebrae*, the adjoining parts of the bodies of the vertebrae, and to fibrous arches that span the concavities of the sides of the upper four vertebral bodies. Thus there is one continuous attachment from the lower border of T12 to the upper border of L5 vertebrae. In addition, the muscle is attached to the medial ends of the transverse processes of the lumbar vertebrae. The muscle passes downwards along the pelvic brim (Fig. 5.43A) and then beneath the inguinal ligament into the thigh, where its tendon is attached to the lesser trochanter of the femur. The lumbar plexus (p. 362) is embedded within the muscle, and part of the external vertebral venous plexus is behind it (in front of the transverse processes). Its lateral border is straight but oblique, running downwards and somewhat laterally; its medial border is slightly curved and just overlaps the pelvic brim, so that a large pregnant uterus displaces it. The genitofemoral nerve emerges from the front of the muscle, the iliohypogastric, ilioinguinal, lateral femoral cutaneous and femoral nerves from its lateral border,

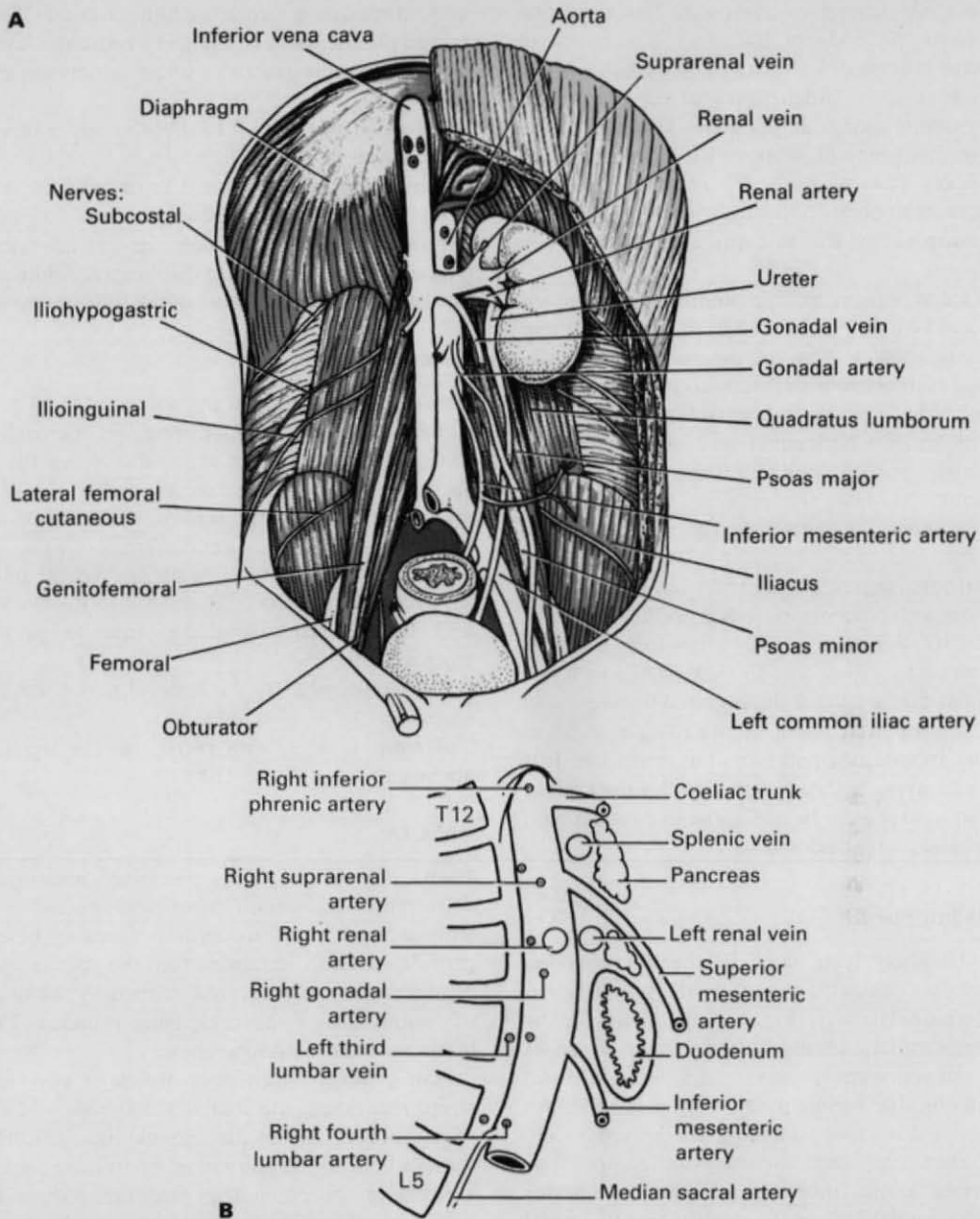


Fig. 5.43 Posterior abdominal wall. **A** Great vessels and nerves. **B** Diagrammatic representation of the aorta as seen from the right side.

and the obturator nerve and the lumbosacral trunk from its medial border. The four lumbar arteries (p. 360) and veins pass beneath the four arches and run laterally behind the psoas muscle; they are accompanied by sympathetic rami (p. 364).

The strong *psoas fascia* (part of the iliac fascia) invests the surface of the muscle, attached to the vertebral

bodies, the fibrous arches, and the transverse processes, and extends along the pelvic brim attached to the iliopubic eminence at the margins of the muscle. It retains the pus of a psoas abscess, and spinal caries may present as a cold abscess in the groin. The sheath is *not* part of the lumbar fascia (p. 358), but the lateral edge blends with the anterior layer of that fascia (over quadratus lumborum).

There is a thickening in the psoas fascia curving obliquely from the body of L1 (or L2) vertebra to the transverse process of L1 vertebra. This is the *medial arcuate ligament*, from which fibres of the diaphragm arise in continuity alongside the crus. The part of the psoas above this ligament is above the diaphragm, i.e. in the thorax. The sympathetic trunk passes from thorax to abdomen beneath this ligament.

Nerve supply. By the first three lumbar nerves, mainly L2.

Action. Its action on the hip joint is described on pages 153 and 168. Being attached to the *sides* of lumbar vertebrae it is a *lateral flexor* of the vertebral column. When acting from below with iliopsoas and their fellows of the opposite side, it assists in the flexion of the trunk produced by anterior abdominal wall muscles (especially rectus abdominis) by pulling on the lumbar part of the column as a whole (rather than by flexing one vertebra on another) while iliopsoas exerts its effect on the hip bone.

Psoas minor, present in only two out of every three individuals, is a slender muscle lying on the surface of psoas major. Its short slender belly arises from T12 and L1 vertebrae and its long tendon flattens out to blend with the psoas fascia behind the inguinal ligament and thus gains a bony attachment at the margin of psoas major to the arcuate line and iliopubic eminence. It is supplied by L1 nerve and its action is to flex the lumbar spine, but so weakly as to be negligible in contrast with psoas major and rectus abdominis.

Quadratus lumborum

This is a flat sheet lying deep in the paravertebral gutter, edge to edge with psoas medially and transversus abdominis laterally (Fig. 5.43A). It lies in the anterior compartment of the lumbar fascia. It arises from the stout transverse process of L5 vertebra, from the strong iliolumbar ligament and from a short length of the adjoining iliac crest. Its fibres pass upwards to the transverse processes (lateral to psoas) of the upper four lumbar vertebrae and, more laterally, to the inferior border of the medial half of the twelfth rib. Its lateral border slopes upwards and medially and so crosses the lateral border of iliocostalis, which slopes upwards and laterally. Its anterior surface is covered by the anterior layer of the lumbar fascia. A thickening in front of this fascia passing from the first lumbar transverse process to the outer end of the twelfth rib constitutes the *lateral arcuate ligament*. The fibres of the diaphragm arise in continuity from the ligament. The subcostal neurovascular bundle (vein, artery, nerve from above downwards) emerges from the thorax beneath the ligament

and slopes down across the lumbar fascia. The muscle represents the inner of the three muscular layers of the body wall and is in series with the innermost intercostal muscles (p. 242).

Nerve supply. By T12 and the upper three or four lumbar nerves.

Action. Its chief action is to prevent the diaphragm from elevating the twelfth rib and so wasting its contraction. By depressing the twelfth rib it aids descent of the contracting diaphragm. Additionally it is an abductor (lateral flexor) of the lumbar spine.

Iliacus

This muscle arises from the hollow of the iliac fossa up to the inner lip of the iliac crest and encroaches across the sacroiliac joint to arise also from the anterior sacroiliac ligament, where it overlies the ala of the sacrum. It is triangular in shape and its fibres converge medially towards the lateral margin of psoas and pass out of the iliac fossa beneath the lateral part of the inguinal ligament. It is inserted into the psoas tendon and the adjacent part of the femur below the lesser trochanter (p. 153).

Nerve supply. By the femoral nerve (L2, 3) in the iliac fossa.

Action. It acts, with psoas, on the hip joint (see above and pp. 153 and 168).

FASCIA

Each muscle of the posterior abdominal wall (quadratus lumborum, psoas and iliopsoas) is covered with a dense and unyielding fascia. These fasciae provide a firm fixation for the peritoneum and retroperitoneal viscera, undisturbed by the movements of contraction of the underlying muscles. The psoas fascia has been described above.

Iliac fascia. The iliopsoas muscle is covered by the strong iliac fascia; this is attached to bone at the margins of the muscle, and to the inguinal ligament. The fascia forms a floor to the abdominal cavity, and serves for the attachment of parietal peritoneum. Apart from its prolongation into the femoral sheath (p. 154) it does not extend into the thigh, for there is no peritoneum there.

Lumbar fascia. Strictly speaking, this is properly called the lumbar part of the thoracolumbar fascia. In the lumbar part of the trunk of the body, three layers of tough fibrous tissue enclose two muscular compartments (Fig. 1.10, p. 19). The anterior and middle layers occupy only the lumbar region, but the posterior layer extends above this to the lower part of the neck (as the thoracic part of the thoracolumbar fascia) and below to the dorsal surface of the sacrum. Quadratus

lumborum occupies the anterior compartment, while erector spinae fills the posterior compartment. The *anterior layer* extends from the front of the iliolumbar ligament and adjoining iliac crest to the lower border of the twelfth rib. Medially it is attached to the front of each lumbar transverse process near its root, adjoining the attachment of the psoas fascia. Laterally it blends with the middle layer along the lateral border of quadratus lumborum; here transversus abdominis and internal oblique take origin. The *middle layer* extends from the back of the iliolumbar ligament and adjoining iliac crest up to the twelfth rib. Medially it is attached to the tips of the lumbar transverse processes. Laterally it blends with both anterior and posterior layers. The latter line of fusion is along the lateral border of erector spinae. Note that quadratus lumborum and erector spinae have lateral borders that slope in opposite obliquities and cross each other like the limbs of a very narrow X. The *posterior layer* lies over the whole erector spinae mass of muscle. It is attached medially to the spinous processes and supraspinous ligaments of all the sacral, lumbar and thoracic vertebrae. Its lateral margin traced from below upwards extends along the transverse tubercles of the sacrum to the ridge on the posterior part of the iliac crest. It slopes outwards to the twelfth rib, being attached across the lumbar region to the middle layer along the lateral border of iliocostalis. Above the twelfth rib its attachment is to the angles of all the ribs; its lateral border over the thoracic cage thus slopes up medially. In the thorax this single posterior layer constitutes the thoracic part of the thoracolumbar fascia; it is only below the thorax where there are no ribs that the thoracolumbar fascia is in three layers. The posterior layer is thick and strong over the lumbar region, being here reinforced by fusion of the aponeurotic origin of latissimus dorsi. Over the thorax it gradually becomes thinner and it fades out above the first rib over the extensor muscles of the neck, where it is replaced by the splenius muscle.

VESSELS

The central vascular features of the posterior abdominal wall are the abdominal part of the aorta and the inferior vena cava, with the vein lying on the right side of the artery.

Abdominal aorta

The thoracic aorta becomes the **abdominal aorta** on passing behind the median arcuate ligament and between the crura of the diaphragm, on the front of the body of T12 vertebra (Fig. 5.43A). It passes downwards on the bodies of the lumbar vertebrae, inclining

slightly to the left, with the left sympathetic trunk at its left margin. On the body of L4 it divides into the two common iliac arteries.

Between the origins of the coeliac trunk and the superior mesenteric artery the aorta is crossed by the splenic vein and the body of the pancreas (Fig. 5.43B). Between the superior and inferior mesenteric origins lie the left renal vein, the uncinate process of the pancreas and the third part of the duodenum. Below the duodenum the aorta is covered by the parietal peritoneum of the floor of the left infracolic compartment (Fig. 5.17).

The *surface marking* of the abdominal aorta is from just above the transpyloric plane in the midline to a point just to the left of the midline level with the highest points of the iliac crests. The *pulsation* of the aorta can usually be felt (and in thin people who are lying down, often seen) in the epigastrium or umbilical regions.

Branches

From its posterior surface at its bifurcation, the small **median sacral artery** is given off, to run in the midline over the sacral promontory into the hollow of the sacrum. This is morphologically the direct continuation of the aorta, vestigial in tailless man but large in creatures such as the crocodile.

The remaining branches of the abdominal aorta fall into three groups: single ventral arteries to the gut and its derivatives (coeliac, superior and inferior mesenteric), paired branches to other viscera (suprarenal, renal and gonadal arteries) and paired branches to the abdominal wall (subcostal, inferior phrenic and lumbar arteries). The gut branches have already been described (p. 319 and later); the remainder are considered below and where appropriate with the viscera concerned.

The **suprarenal arteries** arise from the aorta between its inferior phrenic and renal branches. They run laterally across the crus of the diaphragm; the right artery lies between the crus and the inferior vena cava and behind the bare area of the liver, and the left one is behind the posterior wall of the lesser sac, in the stomach bed. Each artery divides into several small branches before entering the gland (p. 372).

The **renal arteries** are large vessels arising at right angles from the aorta at the level of L2 vertebra (Fig. 5.43). The left artery is shorter than the right; it crosses the left crus and psoas, behind and somewhat above the left renal vein, both of which are covered by the tail of the pancreas and the splenic vessels. The longer right artery crosses the right crus and psoas behind the inferior vena cava and the short right renal vein; these structures separate the artery from the head

of the pancreas and bile duct and from the second part of the duodenum. Each artery approaches the hilum of the kidney to supply the renal segments, as described on page 368 (Fig. 5.49).

Each renal artery gives off small *suprarenal* and *ureteric branches* (pp. 372 and 371).

The **gonadal arteries** have a similar origin and course in both sexes. The **testicular** or **ovarian arteries** arise from near the front of the aorta, below the renal arteries but well above the origin of the inferior mesenteric. They slope steeply downwards over psoas (the right artery first crossing the inferior vena cava), crossing the ureter and supplying its middle portion, and being themselves crossed by the colic vessels and the peritoneum of the floor of the infracolic compartment (Fig. 5.43A). They reach the pelvic brim about halfway between the sacroiliac joint and the inguinal ligament, after which their course is different in the two sexes. The testicular artery runs along the pelvic brim above the external iliac artery, enters the deep inguinal ring and passes in the spermatic cord to the testis (Fig. 5.12 and p. 306). The ovarian artery crosses the pelvic brim and enters the suspensory ligament to pass to the ovary and uterine tube (Fig. 5.59 and p. 391).

The **subcostal arteries** are strictly not branches of the abdominal aorta, having arisen from the lowest part of the thoracic aorta (p. 247), but are mentioned here because each enters the abdomen beneath the lateral arcuate ligament. It runs between the subcostal nerve and vein on the anterior surface of the lumbar fascia over quadratus lumborum behind the kidney, and passes laterally into the neurovascular plane of the anterior abdominal wall (between internal oblique and transversus).

The **inferior phrenic arteries** leave the aorta at the aortic opening and each slopes upwards over the crus of the diaphragm, which they supply. They give off small suprarenal branches (p. 372).

The **lumbar arteries**, four in number, leave the abdominal aorta opposite the bodies of the upper four vertebrae. Hugging the bone they pass *beneath* the lumbar sympathetic trunks and the fibrous arches in the psoas. On the right side the inferior vena cava overlies the lumbar arteries. Each artery gives off posterior and spinal branches and passes laterally through the psoas muscle. The three upper arteries pass laterally *behind* quadratus lumborum muscle into the neurovascular plane between transversus abdominis and internal oblique. The fourth lumbar artery, like the subcostal, passes across to the neurovascular plane in front of the lower border of quadratus lumborum, along the upper margin of the iliolumbar ligament. There is no fifth lumbar artery; its place is taken by the **iliolumbar artery** (from the internal iliac, p. 395). It ascends from

the pelvis in front of the lumbosacral trunk and passes laterally behind the obturator nerve and psoas muscle. The *lumbar branch* supplies psoas and quadratus lumborum and gives a spinal branch which enters the L5–S1 intervertebral foramen. The *iliac branch* runs into the iliac fossa, supplying iliacus and the ilium, and ends in the anastomosis at the anterior superior iliac spine.

The **common iliac arteries** are formed by the bifurcation of the aorta, on the body of L4 vertebra but to the left of the midline, so that the right artery is a centimeter longer than the left. Each passes to the front of the sacroiliac joint where the bifurcation into external and internal iliac arteries occurs; the ureter lies in front of this bifurcation or the very beginning of the external iliac. The left common iliac is crossed by the inferior mesenteric (superior rectal) vessels. Each is also crossed by the sympathetic contributions to the superior hypogastric plexus (p. 365) and covered by the parietal peritoneum of the posterior abdominal wall.

The **external iliac artery** continues in the line of the common iliac, along the pelvic brim on psoas, and passes beneath the inguinal ligament to enter the femoral sheath as the femoral artery. Its two branches are given off just above the ligament. The *inferior epigastric artery* (p. 300) is a key feature at the deep inguinal ring (p. 304) and supplies the rectus muscle (p. 300). The *deep circumflex iliac artery* runs above the inguinal ligament (p. 300; Fig. 5.10).

The *surface marking* of the common and external iliac arteries is from the aortic bifurcation (just to the left of the midline level with the highest points of the iliac crests) along a line slightly concave laterally to the midpoint between the anterior superior iliac spine and the pubic symphysis. The bifurcation of the common into the external and internal iliacs is 3 cm from the midline level with the tubercles of the iliac crests.

The **internal iliac arteries** enter the pelvis and are described on page 394.

Inferior vena cava

The **inferior vena cava** has a longer course than the aorta in the abdomen. It begins opposite L5 vertebra, lower than the bifurcation of the aorta, by the confluence of the two common iliac veins behind the right common iliac artery (Fig. 5.43A). It runs upwards on the right of the aorta beyond the aortic opening in the diaphragm, above which level it lies on the right crus behind the bare area of the liver, and extends to the central tendon of the diaphragm, which it pierces on a level with the body of T8 vertebra (four vertebrae higher than the beginning of the abdominal aorta). It lies on the bodies of the lumbar vertebrae, overlapping the right sympathetic trunk, and crosses the right renal artery.

Above this level it is separated from the right crus by the contiguous edges of the right suprarenal gland and coeliac ganglion, and the right inferior phrenic artery.

At its commencement below, its tributaries lie posterior to the aorta, while, higher up, it and its tributaries lie on a more anterior plane, a result of its development (p. 45).

In the infracolic compartment the inferior vena cava lies behind the peritoneum of the posterior abdominal wall; it is crossed by the root of the mesentery and above this by the third part of the duodenum. In the supracolic compartment it lies at first behind the portal vein, head of the pancreas and bile duct, then behind the peritoneum that forms the posterior wall of the epiploic foramen. Above this it is behind the bare area of the liver, into which it excavates a deep groove.

The *surface marking* of the inferior vena cava is from a point on the intertubercular plane 2.5 cm to the right of the midline to a point 2.5 cm to the right of the xiphisternal joint.

Tributaries

Due to its complex embryological origin, the vena caval tributaries are not identical with the branches of the abdominal aorta. In particular there is none corresponding to the three ventral branches to the gut. The blood from the alimentary tract, pancreas and spleen is collected by the portal venous system, and only after passing through the liver does it reach the vena cava via the **hepatic veins** (p. 346), the vena cava's highest tributaries. Above its formation by the union of the two common iliac veins, the other tributaries (in ascending order) are the fourth and third lumbar veins of both sides, right gonadal vein, both renal veins, right lumbar azygos vein, right suprarenal vein and both inferior phrenics.

Each **common iliac vein** is formed in front of the sacroiliac joint by the union of the internal iliac vein from the pelvis (p. 397) and the external iliac vein, the continuation of the femoral vein, which enters the abdomen on the medial side of its corresponding artery and runs along the pelvic brim behind the artery. The two common iliac veins continue upwards behind their arteries to unite to form the vena cava behind the right common iliac artery (Fig. 5.43A). Because the vena cava is to the right of the midline, the left common iliac vein is longer than the right. It joins its fellow almost at a right angle after bulging forwards across the body of L5 vertebra, and is often compressed by the overlying artery. Each common iliac vein receives *iliolumbar* and perhaps *lateral sacral veins*, while the left usually receives the *median sacral vein* which lies on the right of the corresponding artery.

The **lumbar veins** accompany the lumbar arteries

and drain the lateral and posterior abdominal walls, with anastomotic connections anteriorly with the epigastric veins and posteriorly with the vertebral venous plexuses. The fourth and third empty into the vena cava; those from the left pass behind the aorta, and all are expected to lie behind the sympathetic trunks but occasionally one or more may be in front. The second and first do not usually reach the vena cava but join the *ascending lumbar vein*, which unites common iliac and iliolumbar veins and passes vertically upwards behind psoas and in front of the lumbar transverse processes; that on the right passes through the aortic opening and that on the left perforates the left crus. Each joins the *subcostal vein* to form the **azygos** and **hemiazygos veins** respectively; the *lumbar azygos vein* (see below) may also run into this junction and have connections with the first and/or second lumbar.

The **gonadal veins** accompany the arteries (testicular or ovarian) and each is usually paired. As they run up on psoas the two venae comitantes unite. On the right the vein is usually said to enter the vena cava just below the renal vein, but the right testicular vein may join the renal vein (p. 306); on the left it invariably joins the left renal vein.

The **renal veins** lie in front of the renal arteries and behind the pancreas, and join the vena cava at right angles, at the level of L2 vertebra. Each emerges from the hilum of the kidney as five or six tributaries which soon unite. In length and in territory drained the two veins are *very different*. The *left renal vein* is three times as long as the right (7.5 cm compared with 2.5 cm, 3 in or 1 in), having to cross in front of the aorta. It receives the left suprarenal vein and left gonadal vein, possibly the left inferior phrenic vein, and is connected with the left ascending lumbar and lumbar azygos veins and hence with the azygos and vertebral systems. In contrast the shorter *right renal vein* drains only its own kidney (unless the right testicular vein also enters it — p. 306).

The **right lumbar azygos vein** is a very small vessel, frequently obliterated, connecting the posterior surface of the vena cava at renal vein level with the azygos vein. It lies behind psoas, medial to the ascending lumbar vein. (If present the *left lumbar azygos vein* connects the back of the left renal vein to the hemiazygos vein.)

The **right suprarenal vein** is a very short but stout vessel that enters the vena cava behind the bare area of the liver, where the gland lies in contact with both liver and vena cava (p. 372).

The **inferior phrenic veins** accompany the arteries on the lower surface of the diaphragm and normally join the vena cava just below the liver, but the left vessel may join the left renal or suprarenal vein, or even be double with different destinations.

The three main **hepatic veins** (right, central and left) and several accessory hepatic veins enter the vena cava as it lies in its groove on the back of the liver (p. 346). The hepatic veins have no extrahepatic course, being completely engulfed in liver substance (and hence easily forgotten when trying to recall the vena caval tributaries!).

Lymph nodes and lymph trunks

From nodes which drain the alimentary tract, liver, gall bladder and biliary tract, spleen and pancreas (p. 328), lymphatics pass back along the coeliac, superior and inferior mesenteric arteries to **preaortic nodes** situated around the origins of these three vessels. Similarly, lymphatics pass back along the paired branches of the aorta, both visceral and somatic, to **para-aortic nodes** which lie alongside the aorta at the origins of the paired vessels. The lymph drainage of any viscus follows its artery back to the aorta. Lymph from pelvic viscera drains through nodes along the internal iliac vessels. The lower limb drains by deep inguinal nodes through the femoral canal into nodes along the external iliac vessels. Both these iliac groups drain up to the para-aortic nodes.

The various aortic nodes lie in masses that cannot be readily demonstrated separately by dissection, but clinically their described groups are accurately demarcated from one another.

From the highest of these aortic groups, a variable number of **intestinal and lumbar lymph trunks** (and smaller lymphatics from the posterior ends of the lower intercostal spaces) join to form the elongated, sac-like **cisterna chyli** (though frequently the single cisterna is replaced by a confluence or rete of trunks). It is situated under cover of the right crus, in front of the bodies of L1 and L2 vertebrae, between the aorta and azygos vein. Its upper end becomes continuous with the thoracic duct (p. 279).

Some of the fat absorbed by intestinal cells enters blood capillaries and so reaches the liver directly by the portal vein, but other processed lipid molecules enter the lacteals of the intestinal villi as chylomicrons, so producing the milky-looking lymph which enters the bloodstream via the cisterna chyli and thoracic duct.

NERVES

Somatic nerves

The **lumbar spinal nerves** at their emergence from the intervertebral foramina necessarily pass into the substance of psoas major. They give segmental branches of supply to psoas and quadratus lumborum and then unite to form the lumbar plexus within the substance of psoas (p. 356).

The segmental outflow from the spinal cord continues in series with the intercostal nerves of the thoracic wall. T12 (the subcostal nerve) and all five lumbar nerves emerge in series from the intervertebral foramina, but they do not all share in the supply of the anterior abdominal wall. Only T12 and L1 do so, in fact. L2, 3 and 4, after each giving a branch to the muscles of the posterior abdominal wall (psoas and quadratus lumborum) break up into anterior and posterior divisions which reunite to form nerves for the flexor and extensor compartments of the thigh. Thus is formed the lumbar plexus. The nerves to the thigh are the obturator (for the adductor compartment, a derivative of the flexor compartment of the thigh) and the femoral and lateral femoral cutaneous nerves (extensor compartment). The remainder of L4 and all L5 pass down as the lumbosacral trunk to the sacral plexus for distribution to the lower limb (p. 397).

The **lumbar plexus**, formed from the anterior rami of the upper four lumbar nerves, lies within the substance of psoas major, and its branches emerge therefrom. Most of the branches are for the supply of the lower limb, but in their passage across the posterior abdominal wall they give sensory branches to the parietal peritoneum.

The branches of the lumbar plexus are summarized on page 414.

Nerves for the supply of the anterior abdominal wall cross the anterior surface of quadratus lumborum. They are the subcostal and the iliohypogastric and ilioinguinal nerves (Fig. 5.43A).

The **subcostal nerve** (T12) passes from the thorax behind the lateral arcuate ligament, where it lies below the vein and artery. The whole neurovascular bundle slopes down (parallel with the twelfth rib) across the front of the anterior layer of the lumbar fascia, bound to it by the cellular tissue of the extraperitoneal fascial envelope; here it lies behind the kidney. The subcostal is a large nerve, which disappears by passing through transversus abdominis to reach the neurovascular plane. It slopes down around the anterior abdominal wall, whose muscles it supplies, and ends by supplying the lower part of rectus abdominis and the pyramidalis muscle and the skin above them. Like intercostal nerves it has a collateral (muscular) branch, and its lateral cutaneous branch pierces the oblique muscles and descends over the iliac crest to supply the skin of the anterior part of the buttock between the iliac crest and the greater trochanter.

The **iliohypogastric and ilioinguinal nerves** lie in front of quadratus lumborum at a lower level. They both arise from the anterior ramus of L1. The ilioinguinal nerve represents the collateral branch of the iliohypogastric and consequently has no lateral cutaneous branch (unlike intercostal nerves). The nerves divide from a

common stem. The point of division may be in the psoas muscle or lateral to it, in front of quadratus lumborum. In either case the nerves emerge from the lateral border of psoas major *behind the anterior layer of the lumbar fascia*. As they slope across the quadratus lumborum, behind the kidney, they pierce the fascia and pass laterally in front of it to sink into transversus abdominis and run downwards and forwards, above the iliac crest, in the neurovascular plane.

The **iliohypogastric nerve** gives a lateral cutaneous branch which sinks below the iliac crest to supply skin of the upper part of the buttock behind the area supplied by the subcostal nerve. The nerve then slopes downwards in the neurovascular plane and pierces the internal oblique above the anterior superior iliac spine. Sloping down between external and internal obliques it pierces the aponeurosis of the external oblique about 2.5 cm (1 in) above the superficial inguinal ring and ends by supplying the skin over the lower part of rectus abdominis and the mons pubis.

The **ilioinguinal nerve** represents the collateral branch of the iliohypogastric nerve. It runs parallel with the iliohypogastric at a lower level. Piercing the lower border of internal oblique (Fig. 5.9), it runs downwards and medially and so enters the inguinal canal from the side, continuing behind the external oblique aponeurosis. At the superficial inguinal ring it is covered by the external spermatic fascia which it pierces to become subcutaneous. It supplies the anterior one-third of the scrotum (labium majus), the root of the penis (clitoris), and the upper and medial part of the groin, down to the anterior axial line. Before it perforates the lower border of the internal oblique muscle it gives motor branches to those muscle fibres of internal oblique and transversus which are inserted into the free edge of the conjoint tendon. For the importance of this nerve supply in relation to inguinal hernia, see page 304.

The **lateral femoral cutaneous nerve** is formed by union of fibres from the posterior divisions of the anterior rami of L2 and L3. It usually emerges from the lateral border of psoas major below the iliolumbar ligament, passing around the iliac fossa on the surface of the iliacus muscle *deep to the iliac fascia*. For 3 cm or more (over 1 in) above the inguinal ligament it slopes forward and lies imprisoned in the fibrous tissue of the iliac fascia (Fig. 3.1, p. 147). Fibres of transversus abdominis commonly arise from this fascia, and their contraction may pull on the nerve (meralgia paraesthetica, p. 146). The nerve passes below or perforates the inguinal ligament a centimetre from the anterior superior iliac spine and so enters the thigh. The nerve may arise, not as stated above, but as a branch from the femoral nerve where the latter lies in the iliac fossa in

the gutter between psoas and iliacus. This is not surprising, since the femoral and lateral femoral cutaneous nerves are derived from the same source (*posterior* divisions of the anterior rami of L2, 3, 4 and L2, 3 respectively). The nerve supplies the parietal peritoneum of the iliac fossa. Its peripheral distribution is considered on page 146.

The **femoral nerve** is formed in the substance of psoas major by union of branches from the *posterior* divisions of the anterior rami of L2, 3, 4 (the obturator nerve is formed from the *anterior* divisions of the same nerves). It emerges from the *lateral* border of psoas in the iliac fossa and runs down deep in the gutter between psoas and iliacus *behind the iliac fascia*. It gives two or three branches to iliacus (L2 and 3) and leaves the iliac fossa by passing beneath the inguinal ligament to the lateral side of the femoral sheath, on the iliacus muscle (Fig. 5.43A). Its course in the thigh is considered on page 156.

The foregoing nerves emerge from the *lateral* margin of psoas. The genitofemoral and obturator nerves have each a different pathway.

The **genitofemoral nerve** is formed in the substance of psoas major by union of branches from L1 and 2. It emerges from the *anterior* surface of psoas major (and of psoas minor if present) and runs down on the muscle deep to the psoas fascia. In front of the fascia the left nerve is overlaid by the ureter, gonadal vessels, left inferior colic arteries and the inferior mesenteric vein and the peritoneum of the floor of the left infracolic compartment. The right nerve is overlaid by the ureter, gonadal vessels and the ileocolic artery and the mesentery in the right infracolic compartment. Just above the inguinal ligament it perforates the psoas fascia and divides into genital and femoral branches (Fig. 3.1, p. 147). The genital branch is composed of L2 and the femoral branch of L1 fibres.

The *genital branch* passes through the transversalis fascia and enters the coverings of the spermatic cord (p. 305). It supplies motor fibres to the cremaster muscle, and sensory fibres to the spermatic fasciae, and the tunica vaginalis of the testis. The *femoral branch* passes down in front of the femoral artery, pierces the femoral sheath and the fascia lata, and supplies the skin of the groin below the middle part of the inguinal ligament.

The **obturator nerve** and the lumbosacral trunk emerge from the *medial* border of psoas to enter the pelvis (p. 397).

Autonomic nerves

The abdomen receives both sympathetic and parasympathetic nerves. The sympathetic supply is twofold, by

the lumbar part of the sympathetic trunk and by the coeliac plexus which receives fibres from the thoracic part of the trunk. The coeliac plexus is wholly visceral; it supplies all the *abdominal* organs, including the gonads. The ganglionated lumbar trunk supplies somatic branches for the lower abdominal wall and the lower limb, but its visceral branches supply only the *pelvic* organs. The parasympathetic supply is provided by the vagus from above and the pelvic splanchnic nerves from below; it is wholly visceral. The vagus joins the coeliac plexus and the pelvic splanchnics join the inferior hypogastric plexus. Thus it is better to study the sympathetic plexuses first.

Sympathetic nerves

The **lumbar part of the sympathetic trunk** brings preganglionic fibres descending from the lower thoracic trunk, and it receives a further input of preganglionic fibres (white rami) from the first and second lumbar nerves. Its ganglia give off the regular somatic and visceral branches (p. 30), and the trunk passes down across the pelvic brim to become the sacral part of the trunk (p. 398).

The lumbar part of the sympathetic trunk enters the abdomen by passing behind the medial arcuate ligament on the front of psoas major. Passing in front of the psoas fascia the trunk lies on the vertebral bodies just touching the medial margin of the psoas muscle. As elsewhere it lies in front of the segmental vessels; the

lumbar arteries and veins are expected to pass behind the trunk to reach the fibrous arches in the origin of the psoas muscle but some lumbar veins may pass in front of the trunk — a point to be watched in lumbar sympathectomy (p. 365). The common iliac vessels lie in front of the trunks at the pelvic brim; they are not segmental vessels in series with the lumbar vessels but, in the quadrupedal position, are merely branches of the aorta and vena cava passing ventrally to the pelvis and hind limb, so the sympathetic trunks naturally pass dorsal to them.

The left lumbar trunk lies *along* the left margin of the aorta (Fig. 5.29) with para-aortic lymph nodes in front of it, while the right trunk lies *behind* the inferior vena cava, a result of the asymmetry of the two vessels; the trunks themselves are symmetrically placed in their whole extent.

The **lumbar ganglia** are conventionally four in number, but fusion of ganglia may reduce them. White rami communicantes are received from the first two lumbar nerves and small *accessory ganglia* lie at this level *within the substance of psoas* (Fig. 5.44). Here relay occurs and the grey rami return to the first two (especially the first) lumbar nerves within the substance of the muscle. The other white rami (for the sympathetic trunk itself) pass from the upper two lumbar nerves behind the fibrous arches in psoas. They join the trunk and run down to relay in the lumbar and sacral ganglia, for the somatic and visceral branches therefrom.

Somatic branches (grey rami communicantes) pass from the lumbar ganglia to all five lumbar nerves, for

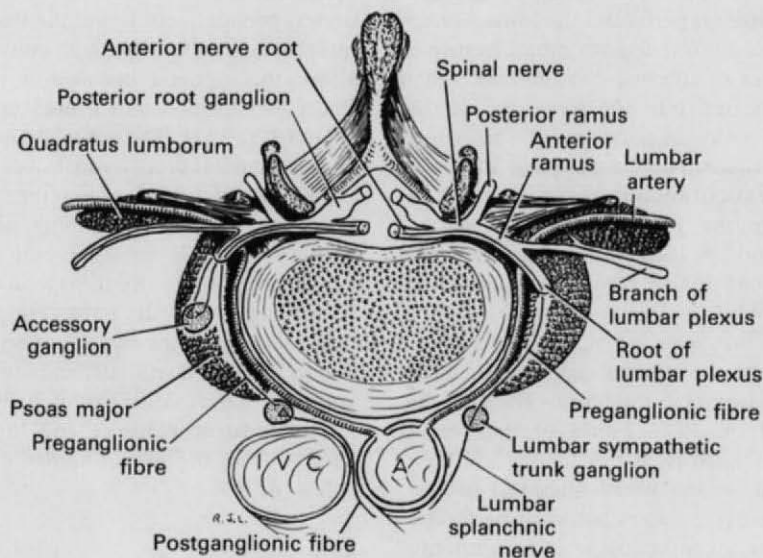


Fig. 5.44 Sympathetic rami at L1 or L2 vertebral levels. An accessory ganglion in psoas major relays directly back to the segmental nerve; the remainder of L1 and L2 outflow passes into the sympathetic trunk for local or distant relay.

distribution to the body wall and lower limb. They accompany the lumbar vessels behind the fibrous arches in psoas. Those for L1 and 2 are very sparse, since almost all the relay at these levels takes place in the accessory ganglia in psoas.

Visceral branches (lumbar splanchnic nerves) arise from all lumbar ganglia to join the coeliac, aortic and superior hypogastric plexuses. Those from the third and fourth ganglia pass respectively in front of and behind the common iliac arteries, so forming loops under those vessels. They join with each other and with fibres from the aortic plexus in front of L5 vertebra to form the **superior hypogastric plexus**. This was previously known as the presacral nerve but was a misnomer: it is prelumbar, not presacral, and is not a single nerve but a plexus. The plexus breaks up into the **right and left hypogastric nerves** (which again may not be single but a bundle) which run down into the pelvis to join the inferior hypogastric plexus (p. 399). There are a few ganglion cells in the superior hypogastric plexus. The preganglionic white fibres in the hypogastric nerves pass through to relay in ganglia in the inferior hypogastric plexuses which supply pelvic viscera. They give no branches to the abdominal viscera, which are supplied by the coeliac plexus.

The **coeliac plexus** lies around the origin of the coeliac trunk above the upper border of the pancreas. The **greater and lesser splanchnic nerves** pierce the crura of the diaphragm and enter the **coeliac ganglia**. These are two semilunar masses, right and left, which overlap the edges of the aorta and encroach laterally on the crura of the diaphragm. Either or both ganglia may be separated into two or more ganglionic masses. The splanchnic nerves are almost all preganglionic (white) and they relay in the coeliac ganglia. The *least splanchnic nerve* relays in a small *renal ganglion* behind the renal artery. This is merely an offshoot of the main coeliac ganglion itself. Separated masses of ganglion may lie on the aorta at the superior and even the inferior mesenteric artery origins. Such irregularity, of separation or of fusion, is common in autonomic ganglia.

From the coeliac ganglia the mass of postganglionic fibres build up a rich network on the aorta, the **coeliac plexus** (Fig. 5.45). The fibres supply all the abdominal viscera, which they reach by streaming along the visceral branches of the aorta. Thus the midline gut arteries (coeliac, and superior and inferior mesenteric) carry sympathetic fibres to the foregut and its derivatives, to the midgut, and to the hindgut down to the lower rectum. Similarly the paired visceral arteries carry fibres from the coeliac plexus. Those passing to the kidney pick up the branches of the renal ganglion to form the renal plexus behind the renal artery. Testis

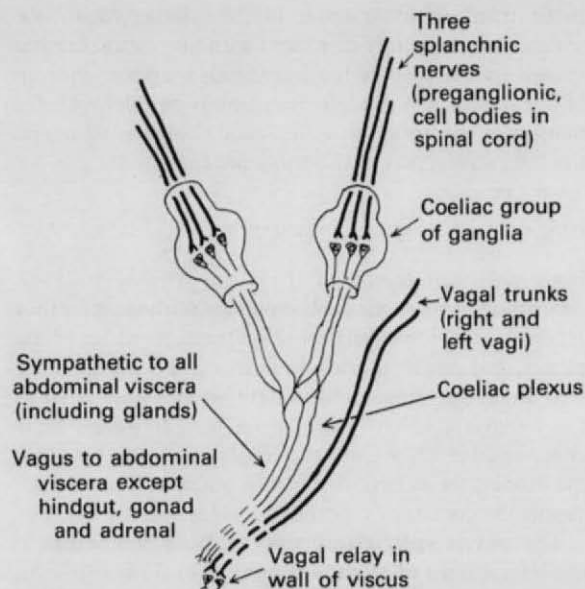


Fig. 5.45 Constituents of the coeliac plexus. The plexus lies distal to the sympathetic relays in the coeliac ganglia. Preganglionic fibres (myelinated) are shown in heavy line, postganglionic (unmyelinated) in slender line.

and ovary are likewise supplied by a sympathetic plexus that accompanies each gonadal artery. Some postganglionic fibres are not used up at the inferior mesenteric artery, in which case they stream down over the aorta to enter the superior hypogastric plexus.

The sympathetic fibres are vasomotor, motor to sphincters (e.g. ileocolic), inhibitory to peristalsis, and carry sensory fibres to all the viscera supplied.

The suprarenal gland has a second supply. Preganglionic fibres from the lesser (or greater) splanchnic nerve pass without relay to the cells of the suprarenal medulla (these cells share a common origin from neural crest ectoderm with the cell bodies of sympathetic ganglia). These preganglionic fibres cause the suprarenal medulla to pour forth adrenalin. The vasomotor supply to the suprarenal gland reaches it by postganglionic fibres from regular relay in the coeliac ganglion.

Lumbar sympathectomy

For removal of the third and fourth lumbar ganglia (p. 33), the approach is through a transverse muscle-cutting incision in the anterior abdominal wall on the appropriate side. The intact peritoneum is stripped off right round to the vertebral column, carefully avoiding damage to the gonadal vessels, ureter and genitofemoral nerve overlying psoas major. The right sym-

thetic trunk is under cover of the inferior vena cava, which must be gently displaced without tearing lumbar vessels (p. 361); some lumbar vessels may pass in front of the trunks. On the left the trunk is parallel with the margin of the aorta. The third and fourth ganglia and the intervening part of the trunk are removed.

PARASYMPATHETIC NERVES

Both vagi, intermixed in the vagal trunks (p. 334), contribute fibres to the coeliac plexus. Without relay they accompany the postganglionic sympathetic fibres of the plexus, but not to the whole territory. To the gut they pass along the foregut and midgut arteries only as far as the transverse colon — no mean feat, however, for a cranial nerve! They enter the renal plexus and pass into the kidney, for a purpose which is obscure. They do not supply the gonads or suprarenals, as far as is known.

The **pelvic splanchnic nerves**, from cell bodies in the lateral horn of sacral segments 2 to 3 or 4 (p. 33), arise from the anterior rami of those sacral nerves distal to the anterior sacral foramina. They anastomose with one another and join the inferior hypogastric plexus for distribution to pelvic viscera. On the left some fibres rise up out of the pelvis, usually passing to the left of the superior hypogastric plexus, to join the inferior mesenteric artery (or make their own way behind the peritoneum) to supply the large intestine from the splenic flexure downwards.

The vagus is motor and secretomotor to the gut and its glands down to the transverse colon; the pelvic splanchnics fulfil this function from the splenic flexure to the rectum.

PART 10

KIDNEYS, URETERS AND SUPRARENAL GLANDS

KIDNEYS

The **kidneys** lie high up on the posterior abdominal wall (Fig. 5.29) behind the peritoneum, largely under cover of the costal margin. At best only their lower poles can be palpated in the normal individual. Each kidney lies obliquely, with its long axis parallel with the lateral border of *psaos major*. On its vascular pedicle it lies well back in the paravertebral gutter, so that the hilum, a vertical slit-like depression at the medial border transmitting the renal vessels and nerves and the renal pelvis (the beginning of the ureter), faces somewhat forwards as well as medially (Fig. 5.48). As a

result of this slight 'rotation' of the kidney an antero-posterior radiograph gives a somewhat foreshortened picture of the width of the kidney. The normal kidney measures about $12 \times 6 \times 3$ cm ($4 \times 2 \times 1$ in) and weighs about 130 g (4 oz). The hilum of the right kidney lies just below, and of the left just above, the transpyloric plane 5 cm (2 in) from the midline; these are the *surface markings* of the hila. The bulk of the right lobe of the liver accounts for the lower position of the right kidney. The upper pole of the left kidney may overlie the eleventh rib in a radiograph, that of the right kidney seldom ascends so high, though it must be remembered that each kidney moves in a vertical range of 2 cm (about 1 in) during full respiratory excursion of the diaphragm.

The kidney possesses a **capsule** which gives the fresh organ a glistening appearance. All surfaces are usually smooth and convex though traces of lobulation, normal in the fetus, are often seen. Thick rounded lips of kidney substance bound the hilum, from which the pelvis emerges behind the vessels to pass down into the ureter.

Posteriorly the relations of both kidneys are similar, comprising mostly the diaphragm and *quadratus lumborum* muscles, with overlap medially on to *psaos* and laterally on to *transversus abdominis*. The upper pole lies on those fibres of the diaphragm which arise from the lateral and medial arcuate ligaments. Thus the **costodiaphragmatic recess of the pleura** lies posteriorly; it is the most important of all posterior relations (Fig. 5.46), and is at risk in the lumbar approach (p. 311). The subcostal vein, artery and nerve, on emerging beneath the lateral arcuate ligament, lie behind the posterior surface of the kidney, as do the iliohypogastric and ilioinguinal nerves as they emerge from the lateral border of *psaos*. (The lateral femoral cutaneous nerve is normally too low to be a posterior relation.) The upper lumbar arteries and veins lie behind the *quadratus lumborum* and thus are more distant from the kidney.

The hilum of the kidney lies over *psaos* and the convexity of the lateral border lies on the aponeurosis of origin of *transversus abdominis*. The suprarenal glands lie somewhat asymmetrically (Fig. 5.29). The right gland, pyramidal in shape, surmounts the upper pole of the right kidney, behind the inferior vena cava and the bare area of the liver, while the left gland, crescentic in shape, is applied to the medial border of the left kidney above its hilum, behind the peritoneum of the posterior wall of the lesser sac.

The anterior relations of the two kidneys are more symmetrical than appears at first sight and may be studied simultaneously with advantage (Fig. 5.29). On each side the peritoneum of the posterior abdominal wall lies in contact with certain areas of the kidney, while intervening structures force it away from the

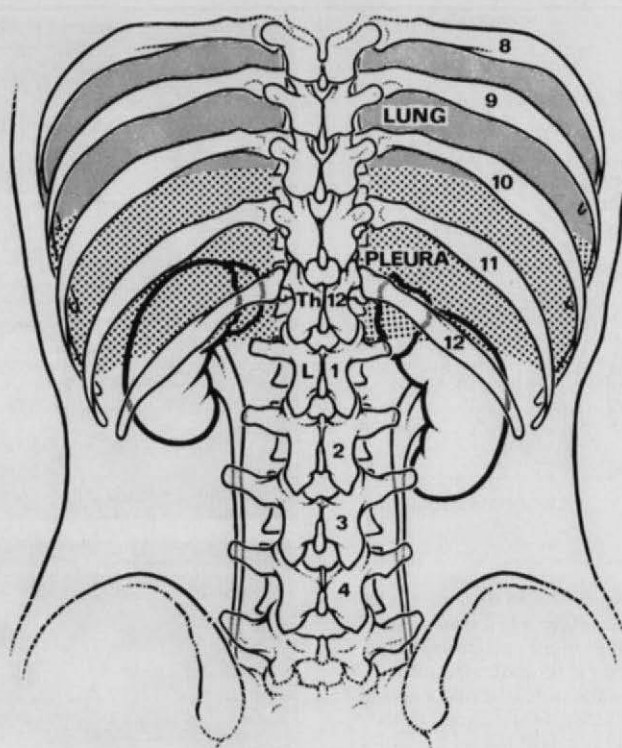


Fig. 5.46 Relationship of the pleural sacs to the upper poles of the kidneys, from behind. The ureters lie medial to the tips of the lumbar transverse processes.

kidney in other areas. The hilum is separated from the peritoneum, on the right side by the second part of the duodenum and on the left side by the tail of the pancreas. The lateral part of the lower pole is separated from peritoneum by the hepatic and splenic flexures of the colon on the right and left sides respectively. The medial part of the lower pole, on each side, lies in contact with peritoneum which separates it from coils of jejunum; here, between peritoneum and kidney, is an artery, the ascending branch of the right colic and of the upper left colic arteries respectively. The upper halves of each kidney, up to the superior pole, lie in contact with peritoneum. On the right kidney is the peritoneum of the hepatorenal pouch (part of the greater sac), in contact with the under surface of the liver. The upper part of the left kidney, over a triangular area between the suprarenal gland, spleen and pancreas, is covered by peritoneum of the lesser sac and so forms part of the stomach bed, with the lienorenal ligament passing forwards near the lateral margin of the kidney (Fig. 5.47).

The **perinephric fat** lies outside the renal capsule (Fig. 5.47) and is, at body temperature, of rather more

solid consistency than the general body fat. It is in the shape of an inverted cone, filling the funnel-shaped hollow of the suprailiac part of the paravertebral gutter, and it plays a part in retaining the kidney in position. The development of nephroptosis ('floating kidney') after severe loss of weight is thus explained.

The **renal fascia** surrounds the perinephric fat and separates the kidney from the suprarenal gland. It is no very obvious membrane in the living, but appears more convincingly in the coagulated dissecting-room cadaver. In truth it is little more than a vague condensation of the areolar tissue between the parietal peritoneum and the posterior abdominal wall, but certain of its attachments are worthy of note, since they serve to restrain the extension of a perinephric abscess. At the hilum of the kidney the fascia is firmly attached to the renal vessels and the ureter, a further factor in stabilizing the kidney and in discouraging spread of pus across the midline. It ascends as a dome between the upper pole of the kidney and the suprarenal, and explains why, in nephrectomy, the latter gland is not usually displaced (or even seen). It is sometimes

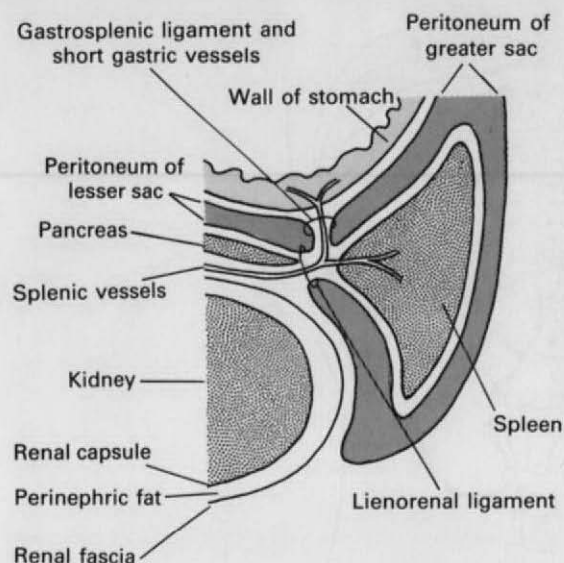


Fig. 5.47 Diagrammatic transverse section through the left upper abdomen, viewed from below (like a CT scan), showing the peritoneal relationships of the spleen and renal fascia. The short gastric vessels run in the gastrospenic ligament. The splenic vessels and the tail of the pancreas are in the lienorenal ligament. The kidney is surrounded by its own capsule, the perinephric fat and the renal fascia.

described as deficient below when traced downwards, but it is complete though weak in this area. Pus in the perinephric space and injections into it do not usually track downwards, but increasing pressure may force the fascia to rupture and allow such contents to flow downwards retroperitoneally towards the pelvis.

The **renal pelvis** is the funnel-shaped commencement of the ureter, and is normally the most posterior of the three main structures in the hilum (though occasionally an arterial branch or venous tributary may lie behind it). Its upper and lower extremities receive two or three major calyces (p. 369). The pelvis, like the ureter, is lined by transitional epithelium and there is smooth muscle as well as connective tissue in its wall. Recent studies suggest that specialized muscle cells in the walls of the minor calyces act as 'pacemakers' that initiate contractile waves which pass down into the ureter. The capacity of the average pelvis is less than 5 ml. Note that its proper name is the renal pelvis, not the pelvis of the ureter.

Blood supply and segments

The wide-bored **renal arteries** (p. 359) have a blood flow in excess of 1 litre per minute. They leave the abdominal aorta at right angles and lie behind the pancreas and renal veins.

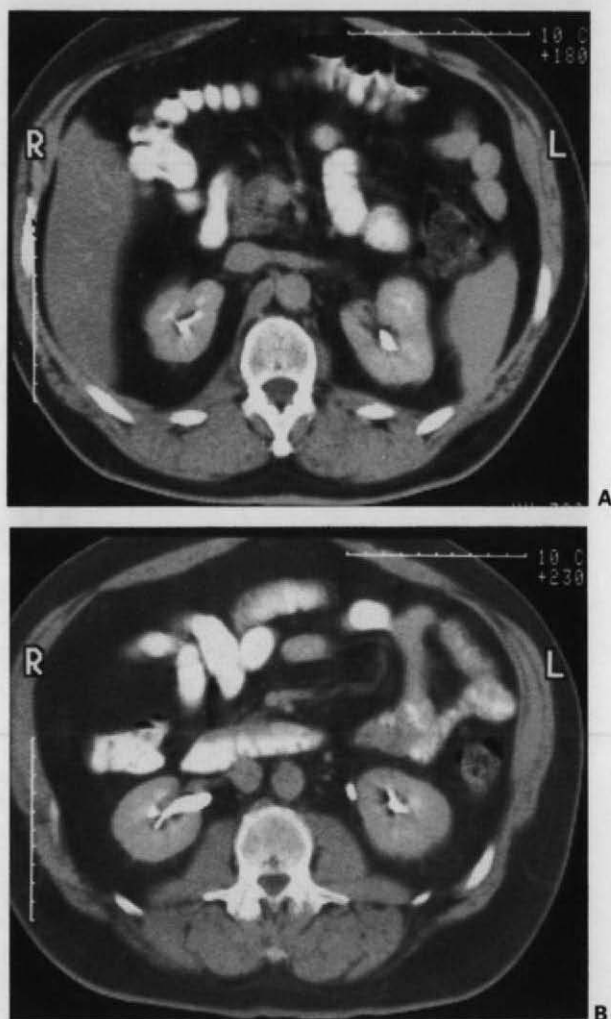


Fig. 5.48 CT scans of the upper abdomen (viewed by convention from below). In **A**, the left renal vein crosses in front of the aorta to enter the inferior vena cava. In **B**, the pelvis of the right kidney is indicated by the white opacity (representing oral contrast medium which has been absorbed and excreted by the kidney), while on the left side the ureter, similarly outlined, lies immediately medial to the lower pole of the kidney.

Based on its blood supply, each kidney possesses five segments. In the region of the hilum the artery typically gives rise to an anterior and a posterior division (Fig. 5.49A). The posterior division supplies the posterior segment, while the anterior division gives branches that supply the apical, upper, middle and lower segments (Fig. 5.49B, C and D). The standard pattern is frequently modified by the way the vessels branch, e.g. the vessels to more than one segment may arise

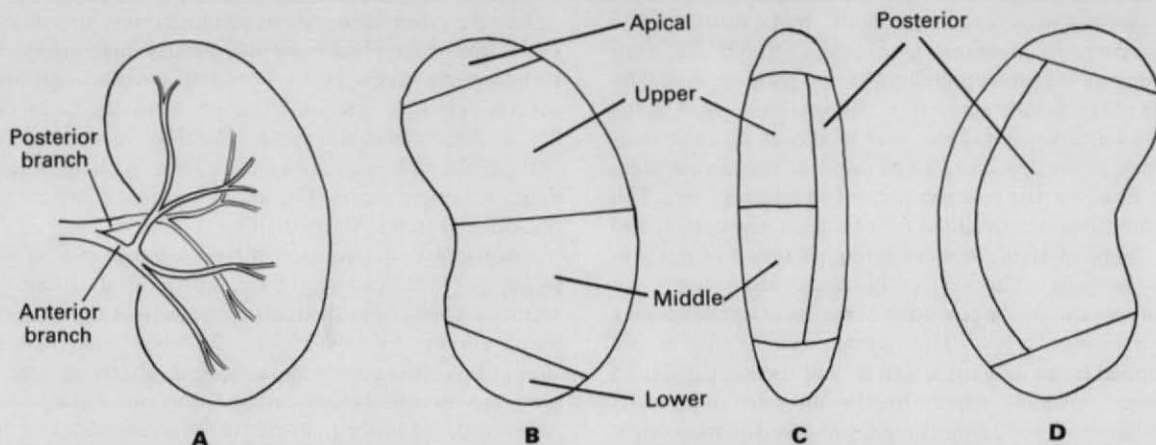


Fig. 5.49 Arterial segments of the left kidney. **A** shows branches of the renal artery; **B**, **C** and **D** indicate the segments as seen from the front, the lateral side and the back respectively. The posterior division of the artery supplies the posterior segment and the anterior division supplies the other four. There may be variations in the pattern of division but the segments are constant.

from a common stem and several variations are possible but there are always five segments with no collateral circulation between them. Abnormal or aberrant renal arteries, such as a vessel running from the aorta to the lower pole are, in fact, segmental vessels with an unusual origin (persistence of a fetal vessel, p. 370). They are not usually accompanied by veins.

Veins from the renal segments communicate with one another profusely (unlike the arteries) and eventually form five or six vessels that unite at the hilum to form the single **renal vein** (p. 361). The usual order of structures in the hilum of each kidney is vein, artery, ureter from front to back.

Lymph drainage

The lymphatics of the kidney drain to para-aortic nodes at the level of origin of the renal arteries (L2). The surface of the upper pole may drain through the diaphragm into nodes in the posterior mediastinum.

Nerve supply

Renal nerves are derived from both parts of the autonomic system. The sympathetic preganglionic cells lie in the spinal cord from T12 to L1 segments and they send preganglionic fibres to the thoracic and lumbar splanchnic nerves. The postganglionic cells are in the coeliac, renal and superior hypogastric plexuses and, for the least splanchnic nerve, in the renal ganglion in the hilum of the kidney. They are vasomotor in function. Afferent fibres, including those subserving pain, accom-

pany the sympathetic nerves as for most other viscera. Thus the pathway for the pain of renal colic from a stone in the calyces or renal pelvis may run along blood vessels to the coeliac plexus and thence by the splanchnic nerves to the sympathetic trunk and via white rami communicantes to T12-L1 spinal nerves and so into the spinal cord by the posterior nerve roots. The pain may radiate from the back and lumbar region to the anterior abdominal wall and down to the external genitalia. There is some parasympathetic supply from the vagus, of uncertain function, but it is possible that some afferents run with the vagal fibres, and this may explain the nausea and vomiting that may accompany renal pain.

Structure

The internal structure of the kidney is displayed when the organ is split open longitudinally. A dark reddish **cortex** lies beneath the capsule and extends towards the pelvis as the *renal columns*, lying between a number of darker and triangular striated areas, the *pyramids* of the **medulla**. The apices of several pyramids open together into a *renal papilla*, each of which projects into a *minor calyx*. The minor calyces unite to form two or three **major calyces** which open into the renal pelvis.

The histological and functional unit of the kidney is the **nephron**, and there are about 1 million in each kidney. Each nephron consists of a glomerulus and a tubule system. The **glomerulus** is a tuft of capillaries surrounded by very thin epithelial cells (podocytes), the whole forming a mass which projects into a rounded *capsule* (of Bowman). The epithelium covering the

capillaries is continuous with that forming the boundary of Bowman's capsule, which in turn continues into the epithelium of the *tubule system*. The part of the tubule adjacent to Bowman's capsule is the *proximal convoluted tubule*, and this leads into the thin-walled *loop of Henle* and so to the *distal convoluted tubule* and finally to the *collecting tubule* and *collecting duct*. The glomeruli and convoluted tubules are in the cortex, and the loops of Henle and collecting tubules and ducts in the medulla. The collecting ducts unite with one another, and the largest open at the tip of a renal papilla in a minor calyx. The glomerular capillaries are supplied by an afferent arteriole, and leaving them is an efferent arteriole which breaks up into peritubular capillaries surrounding the proximal and distal convoluted tubules. Urine is a glomerular filtrate (deproteinized plasma) which passes into the space of Bowman's capsule and so into the tubule system where it is modified by selective absorption and secretion. Certain arteriolar cells and distal convoluted tubule cells constitute the **juxtaglomerular (JG) apparatus**. Arteriolar JG cells of the tunica media secrete renin.

Development

Three separate excretory organs appear in vertebrate evolution — the pronephros, mesonephros and metanephros (p. 36). The first two consist of excretory tubules arranged segmentally and they empty into the same (mesonephric) duct. The third consists of a mass of tubules having no segmental arrangement and it drains into a new duct that develops specifically for the purpose (the ureter).

The **pronephros** (only prominent in embryo fishes) is very evanescent, but its duct persists. **Mesonephric tubules** (which form the excretory organ in fishes and amphibia) then develop and open into the pronephric duct which is henceforth called the **mesonephric (Wolffian) duct** (p. 309). Caudal to the mesonephros the intermediate cell mass gives rise to about a million new tubules, forming the **metanephros**. The latter induces a bud, the ureter, to grow from the caudal end of the mesonephric duct. The **ureteric bud** separates from the mesonephric duct, leaving the latter to form part of the bladder (p. 383) and in the male the ductus deferens and associated structures (p. 309). The bud grows up and divides into the calyces of the pelvis (major and minor) and the collecting tubules of the medullary pyramids, into which the distal convoluted tubules of the metanephros come to drain. The fetal and neonatal kidney has a lobulated appearance, reflecting the way metanephric tissue overlies tubular budding from the calyces.

The definitive kidney (metanephros) develops in the pelvis and is supplied from the internal iliac artery. It subsequently migrates to its adult position, gaining successively new arteries of supply from the common iliac and then from the aorta. The older vessels degenerate as the new ones appear, until the (usually) single definitive artery forms. The hilum is at first anterior but the kidney rotates 90° medially.

Anomalies. Persistence of fetal lobulation is of no significance. Persistence of one of the fetal arteries is common (30% of individuals), especially a vessel from the aorta to the lower pole. Whether such vessels should be called accessory, abnormal, aberrant, supernumerary or whatever is debated. Fusion of the lower poles of the kidneys gives rise to *horseshoe kidney* (1 in 800); the ureters pass anterior to the isthmus of kidney substance, as does the inferior mesenteric artery which limits ascent of the horseshoe. *Polycystic disease* (1 in 500), a hereditary disorder which may be associated with cysts in the liver, pancreas and lungs, is possibly due to incomplete union of renal tubules proper with the collecting tubules of ureteric origin, but the precise cause is unresolved. One person in 500 has only one kidney (*renal agenesis*), a fact which must obviously be confirmed before considering nephrectomy.

Surgical approach

For many operations on the kidney including removal (*nephrectomy*) and removal of stones (*nephrolithotomy*) a lumbar approach is used (p. 311). The renal fascia and perirenal fat are incised to expose the kidney, whose upper pole is freed leaving the suprarenal gland within its own compartment of the fascia. The overlying peritoneum is pushed away forwards and medially. The renal vessels can then be exposed and ligated (the artery before the vein) to mobilize the organ further and transect the ureter. On the right a diseased kidney may adhere to the colon, ureter, duodenum, inferior vena cava or suprarenal gland, and on the left to the colon, ureter, spleen, pancreas and suprarenal. The right renal vein is only 2.5 cm long, so the inferior vena cava is very near the operation area.

For *percutaneous renal biopsy*, the lower pole of the kidney is entered by an approach 2.5 cm below the twelfth rib and at a distance from the midline determined radiologically. Damage to a renal vessel or calyx is a potential hazard, and the needle is only advanced while the patient is holding the breath so that the kidney is not torn by respiratory movement.

For *transplantation*, the donor kidney is placed retroperitoneally in the iliac fossa with the hilum

parallel to the external iliac vessels. The renal artery is anastomosed to the internal or external iliac artery and the renal vein to external iliac vein. The ureter is implanted into the anterior surface of the bladder.

URETERS

The **ureter** is 25 cm (10 in) long. Its points of narrowest calibre are at the pelviureteric junction, at the halfway mark where it crosses the pelvic brim, and at its termination in the bladder mucosa.

The ureter passes down on major psoas under cover of the peritoneum and crosses the genitofemoral nerve, being itself crossed superficially by the gonadal vessels. On the right the upper part is behind the duodenum, while lower down it is crossed by the root of the mesentery and by the right colic, ileocolic and superior mesenteric vessels. On the left it is lateral to the inferior mesenteric vessels and is crossed by the left colic vessels and (just before entering the pelvis) by the apex of the sigmoid mesocolon. It leaves the psoas muscle at the bifurcation of the common iliac artery, over the sacroiliac joint, and passes into the pelvis (p. 383). It adheres to the peritoneum of the posterior abdominal wall when that membrane is stripped up from the psoas fascia. It can be identified from vessels and nerves in the living body by the fact that it is a *whitish cord* which is *non-pulsatile* and which shows *peristaltic activity* when gently pinched with forceps. On the left the apex of the sigmoid mesocolon is the guide to it as it enters the pelvis.

Its **surface markings** are of use in palpating it for tenderness and in identifying radiographic shadows. On the anterior abdominal wall it can be marked from the tip of the ninth costal cartilage to the bifurcation of the common iliac artery. This latter point is found by joining the point of bifurcation of the abdominal aorta (2 cm below and to the left of the umbilicus) to a point midway between the anterior superior iliac spine and the pubic symphysis. The common iliac artery bifurcates one-third of the way down this line.

More important is the line of projection of the ureter on a radiograph. It lies medial to the tips of the transverse processes of the lumbar vertebrae (Fig. 5.46) and crosses the pelvic brim at the sacroiliac joint. From here its pelvic shadow passes to the ischial spine and thence, foreshortened, to the pubic tubercle.

Blood supply

The upper end is supplied by the ureteric branch of the renal artery and the lower end by branches from the inferior and superior vesical and middle rectal (and

uterine) arteries. The middle reaches of the ureter are supplied by branches from the gonadal artery, and, in many cases, by branches from the common iliac as well. All these vessels make a fairly good anastomosis with each other in the adventitia of the ureter, forming longitudinal channels. The blood supply is endangered if the ureter is stripped clean of its surrounding tissue.

The veins of the ureter drain into the renal, gonadal and internal iliac veins.

Lymph drainage

The lymphatics run back alongside the arteries; the abdominal portion of the ureter drains into para-aortic nodes below the renal arteries, the pelvic portion into nodes on the side wall of the pelvis alongside the internal iliac arteries.

Nerve supply

Although sympathetic fibres from T11–L2 segments of the cord reach the ureter via the coeliac and hypogastric plexuses, together with parasympathetic fibres from the pelvic splanchnic nerves, their functional significance is not clear. Intact innervation of the renal pelvis or ureter is not necessary for the initiation or propagation of peristalsis from the calyceal pacemakers. There are no ganglion cells in or on the ureter. Pain fibres accompany sympathetic nerves, as from the kidney (p. 369).

Structure

The ureter is a tube of smooth muscle lined internally by mucous membrane. The muscle often appears histologically to be arranged as a middle circular layer with inner and outer longitudinal layers. However, it is more accurate to consider the muscle as a single coat with fibres running in many different directions because they are parts of intertwining helices. The lax mucous membrane is lined by transitional epithelium; there is no muscularis mucosae. The typical transverse histological section has a characteristic stellate lumen, but in life when containing urine the lumen is round. The outer adventitial layer receives the incoming blood vessels (see above).

Development

The ureter is of mesodermal origin; it is derived by a process of budding from the caudal end of the mesonephric duct (p. 43). Its upper end divides into two or three (the major calyces of the renal pelvis) and further subdivisions produce the minor calyces and

collecting tubules. Low division of the ureteric bud produces double ureter.

SUPRARENAL GLANDS

These glands lie one alongside the upper part of each kidney (Fig. 5.29). They are somewhat asymmetrical and rather yellowish in colour, and lie within their own compartment of the renal fascia. Adrenal gland is an alternative name.

The **right suprarenal gland** is pyramidal in shape and surmounts the upper pole of the right kidney. It lies between the inferior vena cava and the right crus of the diaphragm, its right border projecting to the right of the vena cava and its upper part coming into contact with the bare area of the liver. Only the lower half of it has a peritoneal covering (hepatorenal pouch, greater sac). The right inferior phrenic vessels are near its medial border.

The **left suprarenal gland** is crescentic in shape and drapes over the medial border of the left kidney above the hilum. Its lower pole is covered in front by the body of the pancreas and the splenic artery, the rest of the gland being covered with peritoneum of the lesser sac and forming part of the stomach bed. It lies on the left crus of the diaphragm with the left inferior phrenic artery adjacent. The medial border is to the left of the coeliac ganglion and probably overlapped by the left gastric vessels, with the left greater splanchnic nerve behind it.

Blood supply

Both glands receive blood from three sources: from the inferior phrenic and renal arteries and from the aorta (p. 359). Each source provides several small branches, not just a single vessel. In contrast there is usually a single vein (very rarely double or triple on the right). The right vein is only a few millimetres long and enters the vena cava; the left vein is longer and enters the left renal vein. In each case the suprarenal vein drains into a persisting segment of the subcardinal vein of the embryo (p. 45).

Lymph drainage

To para-aortic nodes.

Nerve supply

The main supply is by myelinated preganglionic sympathetic fibres from the splanchnic nerves via the aortic and renal plexuses; the fibres synapse directly with

medullary cells (p. 30). Blood vessels in all parts receive the usual postganglionic sympathetic supply, although cortical control is not neural but by ACTH from the anterior pituitary.

Structure

To the naked eye a section across the suprarenal resembles a sandwich. Two layers of cortex (the bread) enclose a much thinner layer of medulla (the meat) between them. In places there is no medulla, and the two layers of cortex then meet each other. The **cortex**, whose principal products are cortisol, aldosterone, androgens and related hormones, consists of three layers or zones. Immediately beneath the connective tissue capsule is the *zona glomerulosa*, with small rounded groups of cells. The second layer is the largest of the three, the *zona fasciculata*, consisting of parallel rows of pale-staining vacuolated cells with a high cholesterol content. The innermost *zona reticularis* is a network of smaller and darker-staining cells. The rather small central **medulla** has larger cells secreting the catecholamines adrenaline (80%) and noradrenaline (20%) and some dopamine. Many of the medullary cells exhibit the chromaffin reaction: they contain fine cytoplasmic granules (the catecholamine precursors) which are coloured brown by chromium salts. Dilated capillaries are usually prominent in the medulla but not in the cortex; as in any endocrine tissue, many are present but are collapsed in histological sections.

Development

The medulla is derived by migration of cells from the neural crest and is ectodermal in origin while the cortex is derived in situ from the mesoderm of the intermediate cell mass (p. 36).

Surgical approach

For *suprarenalectomy* (*adrenalectomy*) the glands are usually approached from the front. The right gland is exposed by incising the peritoneum over the upper pole of the kidney. On the left the stomach and spleen are retracted medially; the peritoneum between the splenic flexure of the colon and the oesophageal opening in the diaphragm is incised and a flap of peritoneum stripped medially towards the right with the spleen and its vessels and the tail of the pancreas until the gland is exposed on the medial side of the upper pole of the kidney. On each side the suprarenal vein is ligated before the numerous small arteries; the right vein is particularly short and the vena cava is easily torn. The

glands must be handled as little as possible before venous ligation to prevent surges of hormone release.

PART 11 PELVIC CAVITY

BONY PELVIS

The individual features of the hip bone (p. 215), sacrum (p. 552) and coccyx (p. 554) are considered separately. When articulated the bones enclose a cavity; from the brim of the cavity the ala of each ilium projects up to form the iliac fossa, part of the posterior abdominal wall. The **pelvic brim** is formed in continuity by the pubic crest, pectineal line of the pubis, arcuate line of the ilium, and the ala and promontory of the sacrum. The plane of the brim is oblique, lying at 60° with the horizontal (Fig. 5.51); the vagina is in the same plane. From the brim the pelvic cavity projects back to the buttocks.

The pelvic joints and ligaments are described on page 413.

Sex differences are striking and easily recognized; they are due to the two facts that the female pelvis is broader than that of the male for easier passage of the fetal head and that the female bones, including the head of the femur, are more slender than those of the male. In the **male** pelvis the sturdy bones make an acute subpubic angle (Fig. 5.50), pointed like a Gothic arch, while in the **female** the slender bones make a wide subpubic angle, rounded like a Roman arch. The outline of the pelvic brim differs. In the **male** the sacral promontory indents the outline, and the brim is widest towards the back (a 'heart-shaped' outline) while in the **female** there is less indentation of the outline by the sacral promontory and the brim is widest further forwards (a 'transversely oval' outline). Sex differences in the hip bone (p. 221) and sacrum (p. 554) are equally obvious in the articulated pelvis.

Position of the pelvis

Hold an articulated pelvis in the position it occupies in the erect individual, and note the degree of tilting of the hip bone and sacrum. The anterior superior iliac spines and the upper margin of the symphysis pubis lie in the same vertical plane. Note an important **horizontal plane** — the upper border of the symphysis pubis, the spine of the ischium, the tip of the coccyx, the head of the femur and the apex of the greater trochanter lie in the one plane (Fig. 5.50). This plane passes through the

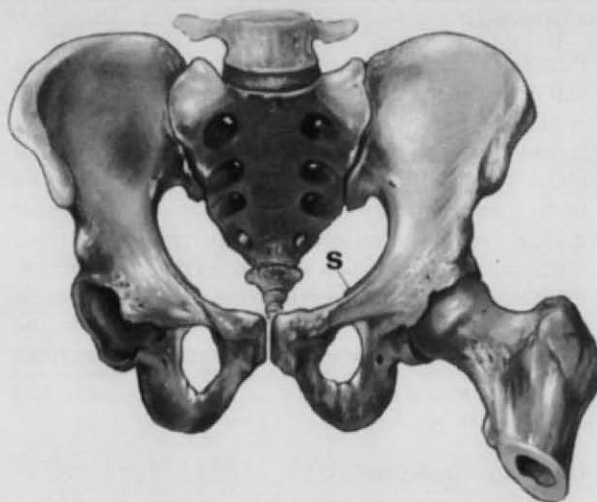


Fig. 5.50 Male pelvis, from the front. An imaginary horizontal plane through the top of the pubic symphysis traverses the tip of the coccyx, the ischial spine (S), the centre of the acetabulum and femoral head, and the tip of the greater trochanter.

pelvic cavity at a level with the tip of the finger of the clinician during rectal or vaginal examination. The ovaries in the female and the seminal vesicles in the male lie in this plane.

PELVIC WALLS

The word pelvis is Latin for a basin and, when properly tilted forwards into the anatomical position, the bony pelvis does bear some resemblance to a pudding basin but with much of the front wall missing. The deficiency is made good by the lower part of the anterior abdominal wall where the aponeuroses of all three anterolateral muscles lie in front of rectus abdominis.

The pelvic brim divides the 'false pelvis' (above the brim, and part of the general abdominal cavity) from the 'true pelvis' or pelvic cavity (below the brim). It is usually clear from the context whether 'pelvis' is being used to describe the bony structure or the cavity.

The muscles of the pelvis are defined as obturator internus and piriformis (which are also classified as lower limb muscles) and levator ani and coccygeus, which, with their fellows of the opposite side, constitute the pelvic floor or pelvic diaphragm (the terms are synonymous).

The side wall of the pelvis is formed by the hip bone, clad with obturator internus and its fascia. The curved posterior wall is formed by the sacrum with piriformis passing laterally into the greater sciatic foramen.

Piriformis

Piriformis arises from the middle three pieces of its own half of the sacrum and the adjoining lateral mass. The origin extends medially between the anterior sacral foramina, so that the emerging sacral nerves and sacral plexus lie on the muscle (Fig. 5.55). It runs transversely to the greater sciatic foramen. The pelvic surface of the muscle and the sacral plexus are covered by a strong membrane of pelvic fascia attached to the sacral periosteum at the margin of the muscle; elsewhere the sacrum presents bare bone. The course of the muscle in the gluteal region, its nerve supply and action are described on page 164.

Obturator internus

Examine the hip bone. The large obturator foramen contains in life a felted mass of fibrous tissue, the obturator membrane (Fig. 5.51), with a gap above that converts the obturator notch into a canal for the obturator nerve and vessels (Fig. 3.55, p. 218). The muscle arises from the whole membrane and from the bony margins of the foramen (Fig. 5.62). The origin extends posteriorly as high as the pelvic brim and across the flat surface of the ischium to the margin of the greater sciatic notch. On the ischial tuberosity the origin extends down to the falciform ridge. From this wide origin the muscle fibres converge fan-wise towards the lesser sciatic notch. Above the notch is a curved

bare area of bone, with a large bursa lying on it beneath the muscle. Tendinous fibres develop on the muscle surface where it bears on the lesser sciatic notch and the bone often shows low ridges and grooves where the tendon takes a right-angled turn to pass into the buttock (Fig. 3.55, p. 218). It is described further on page 165.

Note the extent of the *upper margin* of the muscle. From the pelvic brim at the sacroiliac joint the line slopes downwards along the side wall of the pelvis until anteriorly it lies below the obturator canal. Above this line lies bare bone; below it the muscle is covered with a strong membrane, the obturator fascia. This is attached to bone at the margins of the muscle down to the falciform edge of the sacrotuberous ligament on the ischial tuberosity. The white line for origin of levator ani slopes across the obturator internus fascia (the pelvic cavity is above this line, the ischioanal fossa below it). The posterior surface of the body of the pubis and of the pubic symphysis is bare of both muscle and fascia (Fig. 5.52). Do not confuse the obturator *membrane* (in the foramen) with the obturator *fascia* on the internal surface of the muscle.

PELVIC FLOOR

The **pelvic floor** consists of a gutter-shaped sheet of muscle, the pelvic diaphragm, slung around the midline body effluents (urethra and anal canal and, in the female, the vagina).

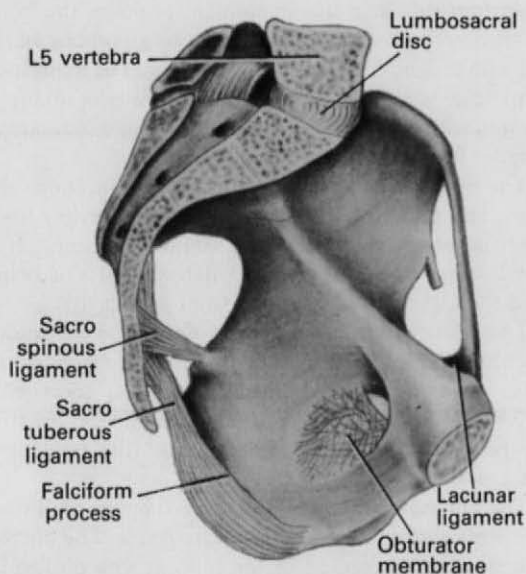


Fig. 5.51 Ligaments of the left half of the pelvis.

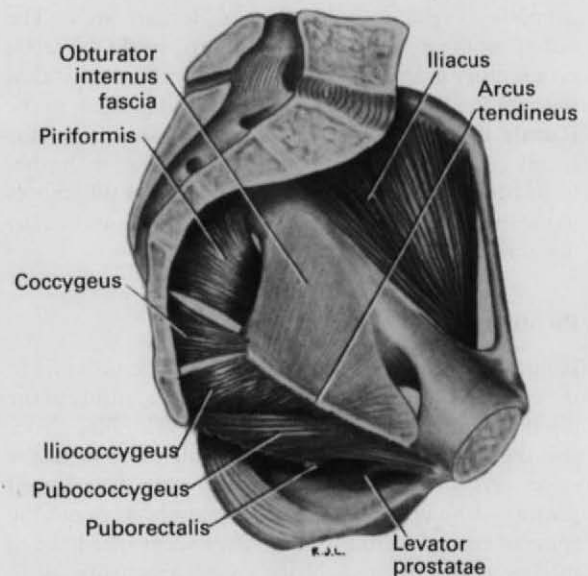


Fig. 5.52 Muscles of the left half of the pelvis.

The muscles of the pelvic floor are called coccygeus and levator ani, but it is better to regard them as one morphological entity, ischiococcygeus, iliococcygeus and pubococcygeus from behind forwards. They arise in continuity from the spine of the ischium, from the 'white line' over the obturator fascia, and from the body of the pubis, and are inserted into the coccyx and the **anococcygeal ligament** (p. 405), a fibromuscular band, the deepest part of which can be called the *anococcygeal raphe*, being formed by interdigitating fibres of levator ani (Fig. 5.53). From their origin the muscle fibres slope downwards and backwards to the midline; the pelvic floor so produced is a gutter that slopes downwards and forwards. Appreciation of this point clarifies the whole of obstetrical mechanics — the lowest part of the fetus is the first to meet this sloping gutter and during delivery is mechanically rotated to the front.

Coccygeus

The human **coccygeus** is best thought of as ischiococcygeus. In the tailed animals this muscle is the 'agitator caudae'. Man has no tail to wag and the muscle is degenerating. Its gluteal surface is, indeed, not muscle, but fibrous tissue, and is none other than the

sacrospinous ligament. It arises from the tip of the ischial spine, alongside the posterior margin of obturator internus. Its fibres fan out to be inserted into the side of the coccyx and the lowest piece of the sacrum; it lies edge to edge with the lower border of piriformis (Fig. 5.52; compare with Fig. 5.51).

Nerve supply. By perineal branches of S4 and S5.

Levator ani

Levator ani consists of two parts, iliococcygeus and pubococcygeus (Fig. 5.53), often separated by a triangular gap. Their fibres arise in continuity, from the ischial spine to the body of the pubis, across the obturator fascia. Here is a thickening, the *white line* or *arcus tendineus* (Fig. 5.52). It is densely adherent to the obturator fascia and is usually described as a thickening thereof. This is not really correct; it is the property of levator ani, not of the obturator fascia. The levator ani originally arose from the pelvic brim (its present origin in most mammals) and in man has migrated down the side wall of the pelvis, bringing the tendinous arch with it; in rare cases the arch hangs free between ischial spine and pubis, with levator ani swinging from it.

The **iliococcygeus** part arises from the posterior half of the white line and the pelvic surface of the *ischial*

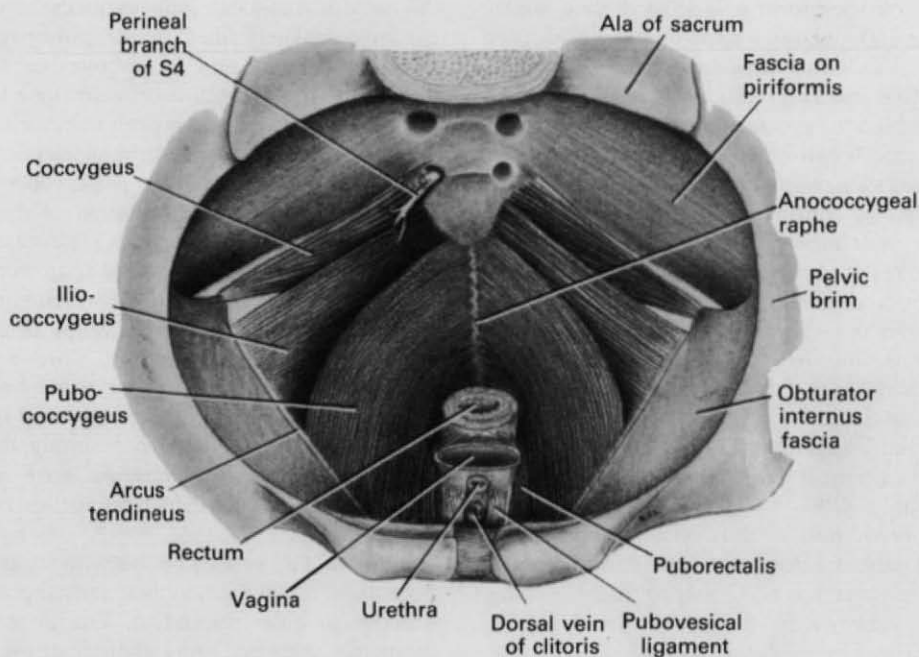


Fig. 5.53 Female pelvic floor from above. The pubococcygeus part of levator ani lies internal to the iliococcygeus part.

spine, and crossing the pelvic surface of coccygeus its fibres are inserted into the side of the coccyx and the anococcygeal ligament and raphe (see above and Fig. 5.53). This extends from the tip of the coccyx to the junction of rectum and anal canal. During defaecation, and especially during the second stage of labour, it is passively stretched.

Note that the iliococcygeus does not arise from the ilium; its name derives from its former origin on the iliac bone at the pelvic brim.

The **pubococcygeus** part is that part of levator ani which arises from the anterior half of the white line and from the posterior surface of the body of the pubis on a level with the lower border of the pubic symphysis (Fig. 5.52). There is often a triangular gap between the adjacent borders of this muscle and iliococcygeus. The pubococcygeus forms a flat muscle whose fibres are in different functional sets. The bulk of its posterior fibres (i.e. those arising from the white line) sweep backwards in a flat sheet on the pelvic surface of the iliococcygeus and are inserted into the tip of the coccyx and the anococcygeal ligament and raphe (Fig. 5.53). These constitute the pubococcygeus muscle proper. Fibres arising more anteriorly, from the periosteum of the body of the pubis, swing more medially and more inferiorly around the anorectal junction and join with fibres of the opposite side and with the posterior fibres of the deep part of the external anal sphincter. No raphe exists here, and the muscles form a U-shaped sling which holds the anorectal junction angled forwards; this part of the muscle is called **puborectalis** (Figs 5.52, 5.54 and 5.65). More medially still, a U-shaped sling of fibres passes behind the prostate into the perineal body; this part is named **levator prostatae**. In the female a similar muscular sling passes behind the vagina into the perineal body, as **pubovaginalis**, or **sphincter vaginae**. The most medial fibres are adjacent to the urethra (p. 393) and can exert some sphincteric action. Do not confuse this 'sphincter vaginae' of the pelvic floor with the sphincter of the introitus (the bulbospongiosus muscles). The puboprostatic and pubovaginal slings are of fibres that interdigitate widely, between the pelvic floor and the skin of the perineum, bound together by fibrous tissue and constituting the perineal body, now called the central perineal tendon (p. 405).

The whole pelvic floor is thus seen to consist of a gutter-shaped muscular diaphragm, the fibres of which are arranged in a series of U-shaped loops sloping progressively downwards towards the midline (Fig. 5.53). The fibres of the U-shaped loops are inserted progressively into the coccyx and the anococcygeal raphe from behind forwards, and when traced in

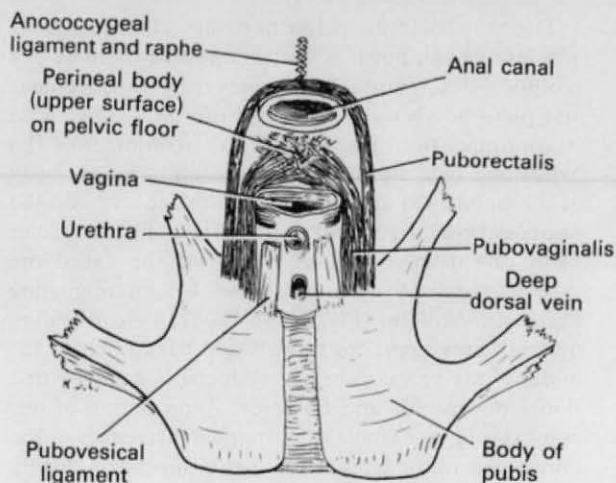


Fig. 5.54 Female pelvic effluents. The pubovesical ligament is attached to the bladder neck (in the male this is the puboprostatic ligament). The pubovaginalis parts of levator ani converge on to the perineal body behind the vagina (in the male, levator prostatae). The puborectalis sling is identical in both sexes, and behind this the anococcygeal ligament and raphe receive the other fibres of levator ani.

this direction the anterior fibres overlap the upper or pelvic surface of the posterior fibres of the raphe.

There is a gap anteriorly between the medial edges of the levator prostate (pubovaginalis) parts. This is almost completely filled by the **puboprostatic ligaments** in the male and the **pubovesical ligaments** in the female. In the midline between these ligaments lies the deep dorsal vein of the penis or clitoris (Fig. 5.54).

Nerve supply. In the light of electrophysiological studies on patients during pelvic operations, long-standing views on the innervation of the pelvic floor must be revised. It now seems clear that all parts of levator ani, including puborectalis, are supplied by the perineal branches of S3 and S4 which enter the upper (pelvic) surface of the muscle. Some of these somatic fibres may travel in or very close to the pelvic splanchnic nerves. The inferior rectal branch (S2) of the pudendal nerve supplies the external sphincter, not levator ani, and S4 does not supply the sphincter. Levator ani, like the external anal and urethral sphincter muscles, has a high proportion of slow twitch fibres.

Actions. The pelvic floor helps to support the pelvic viscera and retain them in their normal positions, and it is active in quiet respiration. The floor contracts to counteract increased intra-abdominal pressure, which may be momentary, as in coughing and sneezing, or more prolonged as in muscular efforts like lifting. If an

expulsive effort is required, the floor relaxes. Thus in defaecation (p. 404) when the abdominal wall and diaphragm contract, puborectalis relaxes to straighten out the anorectal junction and the floor descends to become more funnel-shaped, rising again as the process comes to an end. The pubovaginalis fibres of levator ani may be important in assisting the urethral sphincter at the end of micturition. In parturition the floor initially directs the fetal head to the pelvic outlet, but the degree of stretching to which the muscular and fibrous parts of the floor are subjected renders it liable to damage by tearing, hence the prophylactic use of episiotomy (p. 412).

PELVIC FASCIA

The fascia of the pelvis is usually described under the headings parietal and visceral. Its arrangement is essentially simple, and this simplicity is best appreciated by considering the pelvic fascia under the headings of the pelvic wall, pelvic floor and pelvic viscera. Two principles govern the arrangements of the fascia. The first is that over non-expansile parts the fascia is a strong membrane, while over expansile or mobile parts no membrane exists, the fascia consisting here of a loosely felted areolar tissue. The second principle is that fascia does not extend over bare bone.

The **fascia of the pelvic wall** is a strong membrane which covers the muscles (obturator internus and piriformis) and is firmly attached to the periosteum at their margins. Elsewhere the bone of the pelvic wall is bare of fascia. An exception is the *fascia of Waldeyer*, which sweeps downwards from its attachment in the hollow of the sacrum to the ampulla of the rectum. The spinal nerves lie external to the fascia of the pelvic wall, the vessels lie internal to it. The sacral plexus lies behind the pelvic fascia, between it and the piriformis muscle, and its branches to the buttock do not, therefore, pierce the fascia. The vessels of the buttock (superior and inferior gluteal) on the other hand have to pierce this fascia to establish continuity between pelvis and buttock.

The **fascia of the pelvic floor**, though usually included under the term parietal pelvic fascia, bears no possible resemblance to that of the pelvic wall. Here is no inextensible membrane; indeed such a structure would nullify the necessary mobility of the pelvic diaphragm. The surface of levator ani is covered with no more than the epimysium (loose areolar tissue) that distinguishes muscle surfaces anywhere in the body.

Between the pelvic floor and the pelvic peritoneum lie the pelvic viscera. The extraperitoneal space between these viscera is composed of loose areolar tissue,

which forms 'dead space' for distension of bladder and rectum, and vagina too. The space allows for ready compression during the passage of the fetus in childbirth. Through this loose tissue the infection in pelvic cellulitis travels widely and fast. In the dead-space tissue are found so-called ligaments which are of two types.

First, condensations of areolar tissue surround the branches of the iliac vessels and the branches of the hypogastric plexuses to the viscera. Some of these are very strong. The lateral ligaments of the uterus and bladder and the fascia of Waldeyer are examples of ligaments that form around neurovascular bundles.

Second, certain ligaments exist in their own right, independently of neurovascular bundles. The puboprostatic and pubovesical ligaments are examples. Further examples are the round ligaments of the uterus and the uterosacral ligaments; both contain smooth muscle mingled with their fibrous tissue.

The **fascia of the pelvic viscera** is loose or dense in conformity with the distensibility of the organ. The non-distensible prostate is surrounded by a tough membrane of fascia; the highly distensible bladder and rectum have no membrane around their muscle walls, only a loose and cellular tissue invests them.

PART 12 RECTUM

The Latin word 'rectus' means straight, as if ruled. The **rectum** was originally named in monkeys in which it is straight, but the human rectum appears to be misnamed. Apart from following the posterior concavity of the sacrum and coccyx, it shows three slight lateral curves or flexures that are most prominent when the viscus is distended (Fig. 5.55): upper and lower curves convex to the right and a middle curve convex to the left, the result being that the middle part appears to bulge to the left. The lowest part is slightly dilated as the rectal ampulla. Corresponding to the three curves seen externally, there are three sickle-shaped transverse rectal folds, formerly called rectal valves (of Houston) that project into the lumen. They are produced by the circular muscle of the wall and are not confined merely to the mucous membrane as is the case with the circular folds of the duodenum and jejunum. Their purpose is not clear, but they may be concerned in the separation of flatus from the faecal mass, giving shelf-like support while allowing flatus to pass.

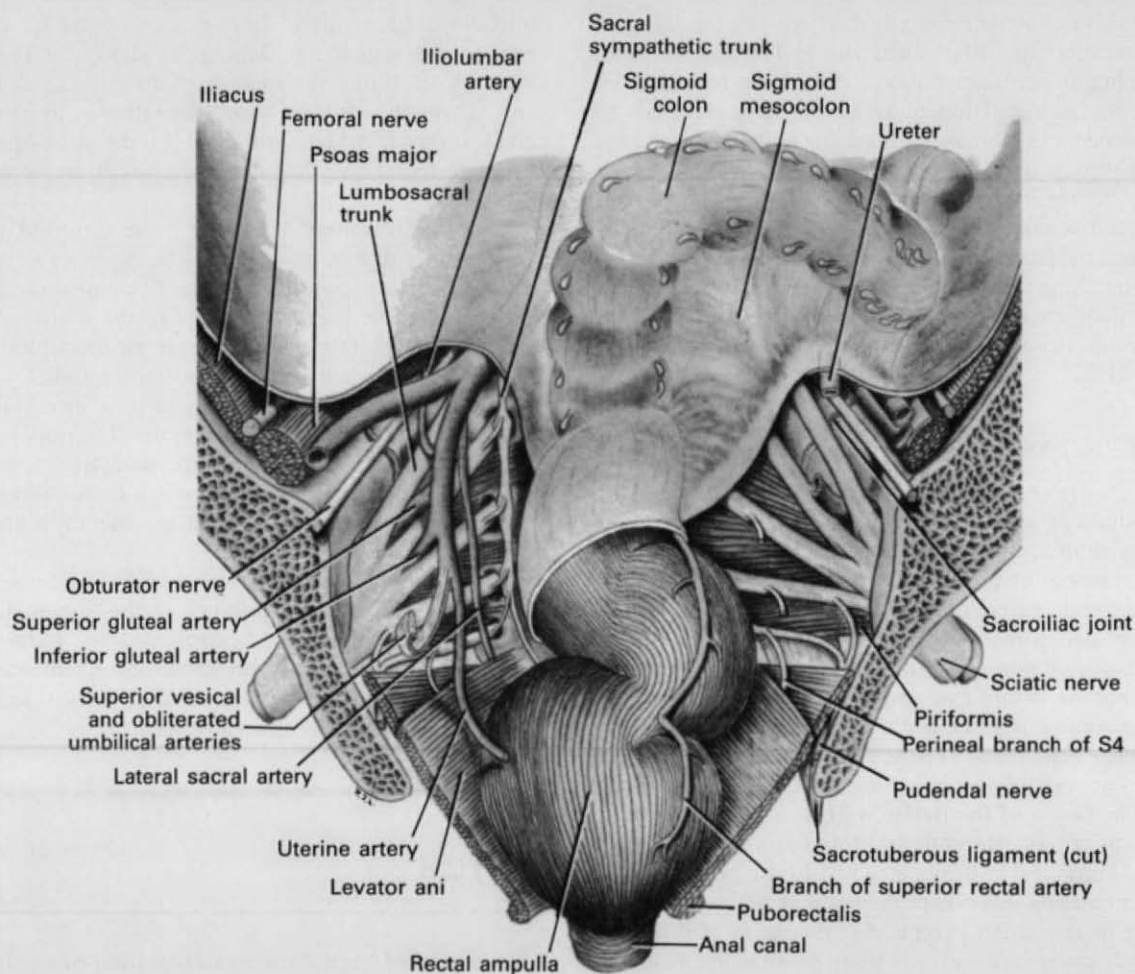


Fig. 5.55 Posterior half of a coronal section of the pelvis.

The rectum, which is about 12 cm (5 in) long, is continuous with the sigmoid colon at the level of the third piece of the sacrum and there is no change of structure at the junction. The distinction is merely a matter of peritoneal attachments; where there is a mesocolon the gut is called sigmoid, where there is no mesentery it is called rectum (compare the duodenum, retroperitoneal, and the jejunum on a mesentery). The rectum ends where its muscle coats are replaced by the sphincters of the anal canal. This is the anorectal junction, and it is slung in the U-loop of puborectalis, which forms a palpable landmark, the *anorectal ring*, on rectal examination (see below).

The three taeniae of the large intestine, having broadened out over the sigmoid colon, come together over the rectum to invest it in a complete outer layer of longitudinal muscle, so there are no sacculations as in

the colon, and also there are no appendices epiploicae. From its commencement in the hollow of the sacrum at the level of the third piece it curves forward over the coccyx and anococcygeal raphe to pass through the pelvic floor into the anal canal just behind the perineal body. The anorectal junction lies at the pelvic floor 3 cm (1½ in) above the cutaneous margin of the anus, at about 5 cm (2 in) from the tip of the coccyx in the position of rest. The anal canal runs from the termination of the rectum to the anal orifice (p. 400); it is in the perineum.

The rectum possesses no mesentery. Peritoneum covers the upper third of the rectum at the front and sides, and the middle third only at the front; the lower third is below the level of the peritoneum which is reflected forwards on to the upper part of the bladder (in the male) or upper vagina to form the **rectovesical**

pouch or **rectouterine pouch** (of Douglas) (Fig. 5.61). These pouches form the lowest parts of the peritoneal cavity, and being 7.5 and 5.5 cm from the anal margins in the male and female respectively are within reach of the fingertip on rectal examination. They are normally occupied by coils of small intestine or sigmoid colon which also lie in the pararectal fossae on either side of the rectum.

In front of the rectovesical pouch is the upper part of the base of the bladder and the tips of the seminal vesicles. Below the level of the pouch are the rest of the bladder base and seminal vesicles, the prostate, and the ends of each ureter and ductus deferens (Fig. 5.56). A condensation of connective tissue, the **rectovesical fascia** (of Denonvilliers) intervenes between this part of the rectum and the structures in front of it. It provides a firm barrier for at least the initial stages of cancerous spread.

In front of the rectouterine pouch is the uppermost part of the vagina (the fornix, with the cervix of the uterus projecting into it), while below the peritoneal reflexion is more of the vagina (Fig. 5.61).

On each side the posterolateral relations of the rectum (Fig. 5.55) include the lower three pieces of the sacrum and the coccyx, the piriformis, levator ani and coccygeus muscles, the anterior rami of the lower three sacral and coccygeal nerves, the sympathetic trunk and pelvic splanchnic nerves, and branches of rectal vessels. The lower part of the rectum is anchored to the curve of the lower sacrum by a condensation of connective tissue commonly known as *Walden's fascia*, while at the sides retroperitoneal tissue round the middle rectal vessels constitutes the *lateral ligaments* of the rectum. These, together with the way that the levator ani muscles become continuous with the external anal sphincter, all help to maintain the rectum in its normal position.

Some muscle fibres leave the lower part of each side of the rectal ampulla and pass forwards to the back of the urogenital diaphragm, behind the rectovesical fascia. They form the rectourethralis muscles which, with the puborectales, must be cut at operations for excising the rectum.

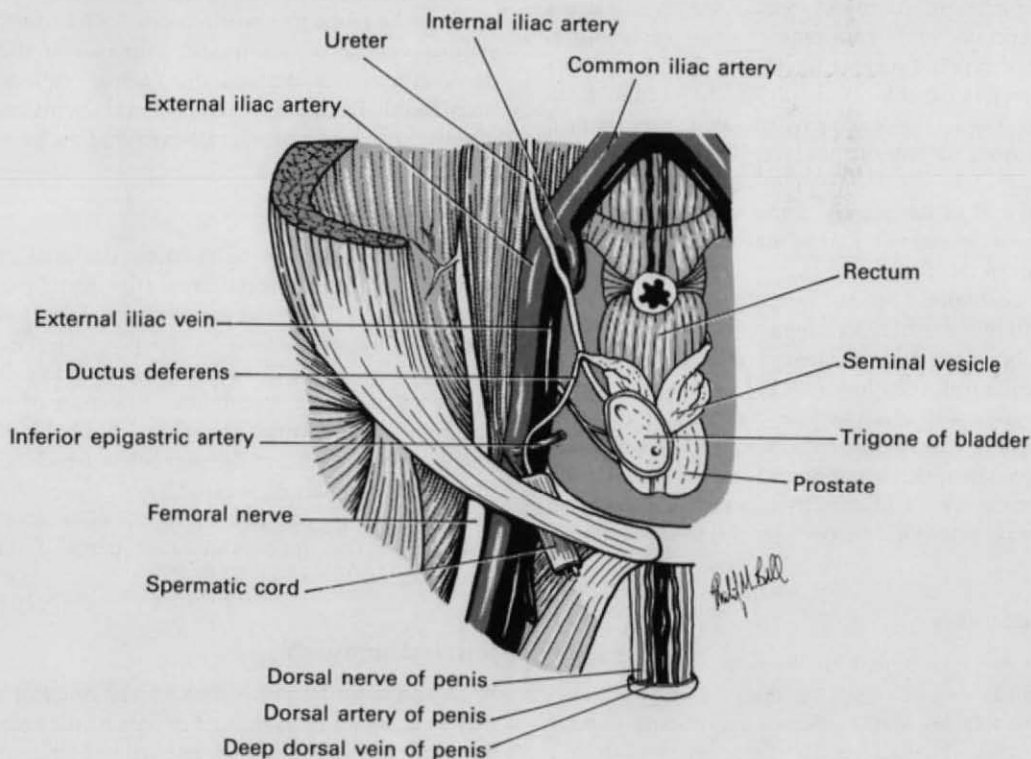


Fig. 5.56 Male pelvic viscera and vessels of the central and left parts of the pelvis. Most of the bladder has been removed, leaving only part of the trigone, in order to display the base of the prostate and the lower part of the left seminal vesicle and ductus deferens.

Blood supply

This is derived principally from the superior rectal artery, with contributions from the middle and inferior rectal and median sacral vessels. The lower end of the inferior mesenteric artery enters the sigmoid mesocolon and changes its name to superior rectal on crossing the pelvic brim. It crosses the left common iliac vessels medial to the ureter and descends in the base of the medial limb of the mesocolon. At the level of S3 vertebra (where the rectum begins) it divides into various branches which, contrary to long-standing opinion, do *not* usually occupy the 3, 7 and 11 o'clock positions as viewed in a patient in the lithotomy position (although these are the positions of the venous cushions in the anal canal — p. 403). These vessels sink into the muscular wall and supply the whole thickness of the rectal wall including the mucous membrane, and continue within the mucosa into the anal canal. The middle rectal arteries, which may be double or absent, reach the lower rectum from the side, along the lateral rectal ligaments, but the inferior rectal vessels penetrate the walls of the anal canal (below the level of levator ani) and their branches run upwards within the walls to reach the rectum. All these vessels supply all layers of the rectum and anastomose with each other. Experience in rectal surgery has shown that the inferior rectal artery is capable of supplying the rectum from below to a level at least as high as the peritoneal reflexion from its anterior surface. The median sacral artery may make an unimportant contribution to the posterior wall in the region of the anorectal junction, but its main interest is that it may cause bleeding at operations in this region.

Veins correspond to the arteries but anastomose freely with one another, forming an *internal rectal plexus* in the submucosa and an *external rectal plexus* outside the muscular wall. The lower end of the internal plexus is continuous with the vascular cushions of the anal canal (p. 403). The middle rectal vein may be very small and insignificant; the superior and inferior rectal veins are the main veins and closely follow their arteries so that drainage is to both the portal and systemic systems.

Lymph drainage

Lymphatics run back with the branches of the superior and middle rectal and median sacral arteries. Lymphoid follicles in the mucous membrane provide the first filter. Thence vessels pierce the wall of the rectum and travel to nodes: (1) in the hollow of the sacrum along the *median sacral artery*, (2) on the side wall of the pelvis along the *middle rectal artery*, and (3)

along the *inferior mesenteric artery* and upwards to the preaortic nodes at the origin of the latter vessel. All these nodes must be removed in the radical extirpation of malignant disease of the rectum.

Nerve supply

The *sympathetic* supply is derived by branches directly from the hypogastric plexuses and by fibres which accompany the inferior mesenteric and superior rectal arteries from the coeliac plexus. The *parasympathetic* supply is from S2 and 3 (or S3 and 4) by the pelvic splanchnic nerves, which are motor to rectal muscle. As from the bladder (p. 382) pain fibres appear to accompany both sympathetic and parasympathetic supplies.

Rectal examination

The structures that can be palpated through the anal canal in either sex are the coccyx and sacrum behind, with the ischial spines and ischioanal fossae at the sides. The anorectal ring can be felt at the anorectal junction as a shelf-like projection over which the tip of the finger can be hooked when the patient bears down. In the male at the front the prostate can be felt (but normal seminal vesicles are not usually palpable). In the female the cervix is felt through the vaginal wall, with the uterosacral ligaments laterally and sometimes the ovaries (compare with vaginal examination, p. 393).

Development

The rectum (with its termination the anal canal) is derived from the anorectal canal (the dorsal part of the cloaca, p. 43). The anal membrane breaks down, at a site probably represented by the pectinate line in the anal canal (p. 402); the anal valves are said to indicate the remains of the membrane. The part of the anal canal continuous with the rectum above the pectinate line is endodermal, and the part below which is derived from the proctodeum is ectodermal, hence the difference in the blood and nerve supplies and lymph drainage of the upper and lower parts of the canal (p. 403).

Surgical approach

With access to the pelvis through the anterior abdominal wall, tumours in the upper part of the rectum can be removed leaving the lower part and the anal canal intact (*anterior resection*). The rectum can be freed by incising the peritoneum at the level of the rectovesical (or rectouterine) pouch and dissecting it away from

surrounding structures. It must be freed from the sacrum by cutting through Waldeyer's fascia, and at the front from the bladder, seminal vesicles and upper part of the prostate (or vagina). The ureters are a hazard, and interference with the hypogastric nerves in the male may cause impotence. The sigmoid colon and mesocolon are transected where required, and the superior rectal vessels ligated usually just below the aortic origin of the inferior mesenteric artery. The descending colon is anastomosed to the remaining end of the rectum.

For complete excision of the rectum and anal canal, the freeing of the rectum as above is supplemented by a perineal approach (*abdominoperineal resection*), which includes dividing the pelvic floor (levator ani). Elliptical incisions either side of the anus allow the ischioanal fossae to be entered so that the tissues in front of the coccyx can be released to open up the space containing Waldeyer's fascia from below. The plane between the rectum and prostate (or rectum and vagina) is defined and opened up, and puborectalis divided to allow the freed bowel to be withdrawn through the perineum. A colostomy is usually made in the left iliac fossa.

PART 13

URINARY BLADDER AND URETERS IN THE PELVIS

URINARY BLADDER

The **bladder** is made of smooth muscle arranged in whorls and spirals — the detrusor muscle. It is adapted for mass contraction, not peristalsis. The muscle is lined by a loose and readily distensible mucous membrane, surfaced by transitional epithelium.

The form and size of the bladder are the same in both sexes. The distended bladder is globular (ovoid) in both sexes, while the empty bladder is flattened from above downwards by the pressure of the overlying intestines.

The standard description of the bladder applies to its undistended state, when it has the approximate shape of a three-sided pyramid with the sharp apex pointing to the top of the pubic symphysis and a triangular base facing *backwards* (like the base of the heart) in front of the rectum or vagina. There are two inferolateral surfaces cradled by the anterior parts of levator ani, a neck where the urethra opens, and a superior surface which is the one that most obviously moves when the bladder fills. There are no hard and fast dividing lines between the various surfaces, especially when distended, but

descriptions of the surfaces are convenient for emphasizing the bladder's position and relations.

The **apex** has the remains of the urachus attached to it, the latter forming the median umbilical ligament which runs up the midline of the anterior abdominal wall in the median umbilical fold of peritoneum (p. 313).

The **base** is the *posterior* surface, most of which in the male has no peritoneal covering, being below the level of the rectovesical pouch; only the uppermost part is covered (Fig. 5.58). On each side of the midline the ductus deferens and seminal vesicle are applied to this surface, and the ureter enters the external surface of the bladder at the upper outer corner. In the female the base has a firm connective tissue union with the anterior vaginal wall and upper part of the uterine cervix with no peritoneum intervening (Fig. 5.61). The lowest part of the base is the trigone (see below).

Each **inferolateral surface** slopes downwards and medially to meet its fellow, lying against the front part of the pelvic diaphragm and obturator internus. Where the surfaces meet below the apex there is a (retroperitoneal) space behind the pubic bones and symphysis, the *retropubic space* (of Retzius), containing loose fatty tissue and also denser condensations that form the pubovesical and puboprostatic ligaments in the male and the pubovesical ligaments in the female.

The lowest part of the bladder is its **neck**, where the base and inferolateral surfaces meet and which is pierced by the urethra at the internal urethral orifice. In the male it lies against the upper surface or base of the prostate (Fig. 5.57). (Note that the base of the prostate is its upper surface but the base of the bladder is its

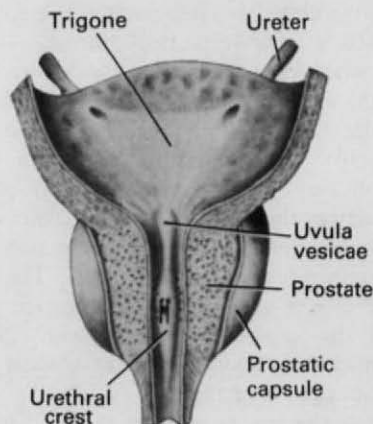


Fig. 5.57 Trigone of the bladder and the prostatic urethra. A bristle emerges from each ejaculatory duct, on either side of the opening of the prostatic utricle.

posterior surface.) In the female the neck is related to pelvic fascia surrounding the upper urethra.

The **superior surface** is covered by peritoneum which sweeps upwards on to the anterior abdominal wall. The rising bladder strips peritoneum from behind rectus abdominis, for the fascia transversalis is here loose and tenuous; the distended bladder may be approached by needle or knife above the pubic symphysis without entering the peritoneal cavity. At the back of this surface in the male the peritoneum continues into the rectovesical pouch, but in the female it is reflected on to the under surface of the uterus as the vesicouterine pouch, failing to reach as far back as the vaginal fornix (Fig. 5.61). The body of the uterus thus rides up and down on the filling and emptying bladder.

The appearance of the interior of the bladder depends upon the state of distension of the organ. When collapsed the mucous membrane is thick and thrown into folds, when distended it is thin and smooth. The trabeculae of the muscle fibres can be seen through the mucous membrane. These remarks do not apply to the trigone, which varies but little with the state of distension of the organ.

The **trigone** is a triangular area at the base of the bladder lying between the *internal urethral orifice* (centrally and below) and the two *ureteral orifices* (above and laterally) (Fig. 5.57). In the empty bladder these three openings are 2.5 cm apart from each other but when distended (as during cystoscopy) the ureteral orifices may be 5 cm apart. Being fixed on top of the prostate by the urethra, the trigone is the least mobile part of the bladder. In the female it is stabilized by the connective tissue (pelvic fascia) surrounding the upper urethra at the front of the vagina. The trigone is smooth walled and the mucous membrane is rather firmly adherent to the underlying muscle. The ureteric orifices are connected by a transverse ridge, the *interureteric bar*, prominent when viewed through the cystoscope. The orifices of the ureters lie at the ends of the bar; they are usually in the shape of an oblique slit, but considerable variations exist. The ureters pierce the muscle and mucosal walls very obliquely; more than any sphincteric muscular action the valve-like flap of mucosa thus produced is the important factor in preventing reflux of urine when intravesical pressure rises. The ureteric orifices are closed by this pressure, except to open rhythmically in response to ureteric peristalsis each time a jet of urine is injected into the bladder (four or five times a minute normally).

In the male the trigone overlies the median lobe of the prostate which, after the first flush of youth, may project above the internal urethral orifice as a rounded elevation, the **uvula vesicae** (Fig. 5.57).

Blood supply

The superior and inferior vesical arteries provide most of the arterial blood but there are small contributions to the lower part of the bladder from the obturator, inferior gluteal, uterine and vaginal arteries. The superior vesical vessels often raise a small 'mesentery' of peritoneum running from the side wall of the pelvis to the upper part of the bladder.

The veins of the bladder do not follow the arteries. They form a plexus that converges on the *vesicoprostatic plexus* in the groove between bladder and prostate and which drains backwards across the pelvic floor to the internal iliac veins. There is a similar plexus in the female, communicating with veins in the base of the broad ligament.

Lymph drainage

The lymphatics of the bladder follow the arteries backwards to internal and external iliac nodes.

Nerve supply

Parasympathetic fibres which provide the main motor innervation of the bladder reach it via the *pelvic splanchnic nerves* (pp. 33 and 398). Sympathetic fibres come from L1 and 2 segments of the cord via the superior hypogastric and pelvic plexuses. For most of the bladder the sympathetic fibres are vasomotor and probably inhibitory to the detrusor muscle, but as noted above they supply the superficial trigonal muscle and (in the male) the internal sphincter. The sensation of normal bladder distension travels with parasympathetic fibres and in the spinal cord is conveyed in the gracile tract, but it appears that bladder pain (e.g. from a stone) reaches the spinal cord (lateral spinothalamic tract) by both parasympathetic and sympathetic pathways.

Control of micturition

Normal emptying of the bladder occurs by contraction of the detrusor muscle and reciprocal relaxation of the external sphincter and pelvic floor (*levator ani*). The accumulation of urine distends the bladder wall with adjustment of tone (*accommodation*) so that tension does not at first increase. Later increased tension stimulates stretch receptors from which afferent impulses pass along the pelvic splanchnic nerves to sacral segments of the cord. Here the parasympathetic cell bodies are in turn stimulated and efferent impulses travel down the pelvic splanchnic nerves to synapse

with the postganglionic cells within the bladder wall and so cause contraction. This *autonomic stretch reflex* giving bladder control at the spinal level is typical of the infant; with training, control by higher centres becomes superimposed on the spinal activity, and bladder evacuation is assisted by voluntary contraction of abdominal muscles. There is a *cortical inhibitory centre* in the middle frontal gyrus (on the medial surface of the cerebral hemisphere, some distance in front of the motor 'perineal' area) with fibres passing to a *detrusor motor centre* in the medial part of the pontine reticular formation. From there reticulospinal fibres run down the cord mixed with those of the lateral corticospinal tract to the sacral segments.

The external sphincter of skeletal muscle (p. 393 female, p. 406 male) is controlled by the perineal branch of the pudendal nerve (p. 411) which is derived from anterior horn cells of approximately the same cord segments that gave origin to the pelvic splanchnic nerves (S2, 3, 4) and the sphincter relaxes as the detrusor contracts. In the female the continuity of smooth muscle from the bladder into the longitudinal muscle of the urethra accounts for the funnel-shape of the upper urethra produced when the bladder contracts. The pubovaginalis part of levator ani (p. 376) assists the external sphincter at the end of micturition.

In spinal cord transection above the level of S2 segment, afferent impulses indicating distension cannot reach consciousness, cortical control of the sacral reflex is lost, and relaxation of the external sphincter cannot be prevented. Because the 'sacral centre' itself is intact, the bladder automatically empties when distended, as in the infant (or as in the senile where cortical control has been lost through cerebral vascular disease). If the sacral segments themselves are destroyed, the detrusor muscle is paralysed and the bladder becomes abnormally distended until overflow incontinence occurs.

Structure

The smooth muscle of the bladder wall (*detrusor muscle*) is composed of an interlacing network of fibres running in various directions. Both externally and internally (beneath the mucous membrane) they produce a trabeculated appearance. They are well supplied by parasympathetic (cholinergic) nerve fibres. However, the trigone possesses a superficial triangular layer of muscle (*superficial trigonal muscle*) that is histologically and histochemically different from the rest of the bladder musculature (including the deep part of the trigone) and extends into the proximal urethra in both sexes (p. 393). In further contrast to the detrusor muscle, the superficial trigonal muscle receives

predominantly sympathetic (adrenergic) fibres. The significance of this distinctive patch of muscle is not clear but it may help to close the ureteral orifices.

At the internal urethral orifice in the male, circular smooth muscle fibres provide an *internal urethral sphincter*. The muscle is continuous with the smooth muscle of the prostate and seminal vesicle, and like the superficial trigonal muscle is profusely supplied with sympathetic (adrenergic) fibres. In the *female* the muscle in this region is arranged longitudinally so there is *no* internal sphincter. This is in keeping with modern views on the function of this part of the urogenital tract: in the male the sphincter acts to prevent seminal regurgitation into the bladder during ejaculation, and has nothing to do with urinary continence.

The mucous membrane is thick and lax and lined by transitional epithelium. It has no glands; mucus in shed urine has come from urethral glands. There is no *muscularis mucosae*.

Development

The endoderm of the vesicourethral part of the urogenital sinus (p. 43) becomes the bladder epithelium, and the surrounding mesenchyme forms the muscle and connective tissue. Continued growth leads to the incorporation of the lower ends of the mesonephric ducts (mesodermal) and their ureteral buds into the posterior part of the bladder, so forming the trigone. These developmental differences may account for the structural differences in this region (see above). The mesonephric ducts end up at a lower level as the ejaculatory ducts entering the urethra (p. 385). The allantois regresses to form a fibrous cord, the urachus (median umbilical ligament, p. 381).

URETERS IN THE PELVIS

The **pelvic part of the ureter** forms about half of its 25 cm (10 in) length (p. 371). It crosses the pelvic brim in the region of the bifurcation of the common iliac artery. On the left it underlies the apex of the sigmoid mesocolon — a readily identifiable guide to it (Figs 5.55 and 5.61). It usually runs *over* the *external* iliac artery and vein and then down the side wall of the pelvis (Fig. 5.56) in *front* of the *internal* iliac artery (and behind the ovary). In order from above downwards, it crosses the obturator nerve, obliterated umbilical (superior vesical) artery, obturator artery and obturator vein. On the right the appendix, if in a pelvic position, may lie adjacent. Reaching the level of the ischial spine, it turns forwards and medially above the pelvic floor to enter the base of the bladder at its upper lateral angle.

Here *in the male* the ductus deferens crosses the ureter superficially and then runs down medial to the ureter. The upper end of the seminal vesicle usually lies just below the point where the ureter enters the bladder wall.

On the pelvic floor *in the female*, the ureter lies in the base of the broad ligament (p. 390), adhering to its posterior peritoneal layer where it is crossed superficially by the uterine artery (Fig. 5.59). The ureter and artery may lie parallel to each other for some little distance before crossing. Under the broad ligament it is at first on the surface of, and then penetrates, the condensed tissue that forms the lateral cervical ligament (p. 390), crossing the lateral vaginal fornix 1–2 cm from the cervix before entering the bladder in front of the fornix. The ureters are major hazards during hysterectomy, when ligating vessels and transecting ligaments.

In both sexes the ureters run obliquely through the bladder wall for 1–2 cm before reaching their orifices at the upper lateral angles of the trigone.

Note that in each sex only one structure lies superficial to the ureter in the pelvis — the ductus deferens or the uterine artery.

The blood and nerve supplies are considered on page 371 and the development above and on page 371.

PART 14

MALE INTERNAL GENITAL ORGANS

PROSTATE

This glandular organ lies beneath the bladder and above the urogenital diaphragm, and is penetrated by the proximal part of the urethra. It is normally broader than it is long (like the caecum), approximately $4 \times 3 \times 2$ cm, and roughly the size and shape of a chestnut. It is clasped on each side by the levator prostatae part of levator ani. Its female homologue is the small group of paraurethral glands (of Skene, p. 393). The prostate provides about 30% of the volume of seminal fluid (most comes from the seminal vesicle).

The prostate has a base and an apex, and anterior, posterior and inferolateral surfaces. The **base** is the upper surface (unlike the bladder, whose base is its posterior surface), fused with the neck of the bladder and perforated by the urethra which traverses the whole length of the gland (Fig. 5.57). The blunt **apex** is the lowest part, and the prostatic urethra emerges from the front of the apex to become the membranous urethra which penetrates the urogenital diaphragm (p. 406). The

anterior surface is at the back of the retropubic space and is connected to the bodies of the pubic bones by the puboprostatic ligaments. The **inferolateral surfaces** are clasped by the levator prostatae parts of levator ani, while the posterior surface, which has a vertical median groove palpable on rectal examination, is in front of the lower rectum but separated from it by the rectovesical fascia (p. 379). The ejaculatory ducts pierce the posterior surface just below the bladder and pass obliquely through the gland for about 2 cm to open into the prostatic urethra about halfway down. The prostate's own ducts also open into this part of the urethra (see below).

A thin layer of connective tissue at the periphery of the gland forms the 'true capsule' of the prostate, and outside this there is a condensation of pelvic fascia forming the 'false capsule'. Between these two capsules lies the prostatic plexus of veins. A third or 'pathological capsule' is described when tumour tissue compresses the normal surrounding part; if benign, the growth can be 'shelled out' from this compressed capsule.

Lobes and structure

The gland consists of acini of varying shapes and sizes embedded in a fibromuscular stroma — a mixture of connective tissue and smooth muscle; this is the characteristic histological feature. Numerous small ducts open into the prostatic urethra (see below).

It is customary to consider the gland as being made up of five lobes — anterior, middle, posterior and two lateral — but there is usually no clear distinction between them. The **anterior lobe** is the small area in front of the urethra; it is unimportant, consisting almost entirely of stromal tissue with few acini. The **middle lobe** is the region between the ejaculatory ducts and the proximal urethra, and is of great importance since, when affected by benign hypertrophy (the common 'enlarged prostate' of the over 50s), it elongates and obstructs the urethra. Minor degrees of hypertrophy of this lobe without urethral obstruction cause a small swelling (the uvula vesicae) at the apex of the trigone of the bladder. The rest of the gland at the back and sides forms the combined **posterior and lateral lobes**, which are best regarded simply as *right* and *left* lobes, and again are important not only because of simple enlargement but as the commonest sites of cancerous change. Enlargement of the lateral lobes may be detected on rectal examination but middle lobe enlargement extending forwards into the bladder will not be. Benign hypertrophy of the prostate is usually not a generalized enlargement but a local adenomatous

proliferation in the 'internal zone' or central region of any of the lobes adjacent to the urethra — the region of the so-called mucosal or periurethral glands. The acini in the much larger outer or peripheral zones of any lobe are the ones affected by carcinoma.

The **prostatic urethra** extends from the internal urinary meatus to the apex of the prostate and is the widest part of the urethra. It is characterized posteriorly by a midline longitudinal ridge, the **urethral crest**. In the middle of the crest is a small swelling, the **seminal colliculus** (verumontanum), on which opens the **prostatic utricle** (utriculus masculinus), an embryonic remnant about 0.5 cm long resulting from union of the caudal ends of the paramesonephric (Mullerian) ducts; it is thus the homologue of the uterus. Alongside it, on the urethral crest, the *ejaculatory ducts* open. The *prostatic ducts* open on the crest and in the sulcus on each side (Fig. 5.57).

Blood supply

The main arterial supply is from the prostatic branch of the inferior vesical artery, with some small branches from the middle rectal and internal pudendal vessels passing to the lower part, but sometimes the middle rectal provides the major supply. The veins run into a plexus between the true and false capsules and this joins the vesicoprostatic plexus situated at the front and sides of the groove between bladder and prostate. At the front, this plexus receives the deep dorsal vein of the penis, and drains backwards into the internal iliac veins.

Lymph drainage

The lymphatics of the prostate pass across the pelvic floor to internal iliac and sacral nodes but some may reach external iliac nodes.

Nerve supply

The acini receive parasympathetic (cholinergic) innervation from the pelvic splanchnic nerves (p. 398), but this is much less important than the muscle fibres of the stroma which contract to empty the glands during ejaculation (p. 411) and which are under sympathetic (adrenergic) control from the inferior hypogastric plexus (p. 399).

Development

The pelvic part of the endodermal urogenital sinus (p. 44) gives rise to lateral epithelial buds which become the prostatic acini of the outer zone. Dorsal

outgrowths from above the level of entry of the mesonephric ducts form the acini of the inner zone. The fibromuscular stroma develops from the surrounding mesenchyme. The different sites of origin of the inner and outer zone acini may account for the different sites of incidence of benign and malignant disease.

Surgical approach

Most operations for the removal of prostatic adenomata are now carried out by the transurethral route, with the resectoscope being passed along the urethra to a point proximal to the seminal colliculus (verumontanum) so that the external urethral sphincter, which is distal to it, is not damaged during the resection. An approach through an abdominal suprapubic incision into the retropubic space gives a wide exposure of the organ.

DUCTUS DEFERENS AND SEMINAL VESICLE

The origin of the **ductus deferens** as the continuation of the epididymis has been considered on page 307. It enters the abdomen at the deep inguinal ring and passes along the side wall and floor of the pelvis to reach the back of the bladder (Fig. 5.56). In its course *no other structure intervenes between it and the peritoneum*.

After hooking around the interfoveolar ligament and inferior epigastric artery at the deep inguinal ring. (Fig. 5.10) it crosses the external iliac artery and vein, obliterated umbilical artery and the obturator nerve, artery and vein, lying on the obturator fascia and always covered by peritoneum. It curves medially and forwards, *crosses above the ureter* and approaches its opposite fellow. The two ducts now turn downwards side by side (Fig. 5.58) and each dilates in fusiform manner. This dilatation is the **ampulla**, the storehouse of spermatozoa; the proximal part of the ductus absorbs fluid produced by the seminiferous tubules of the testis, and the ductus itself makes only a small contribution to the volume of seminal fluid. The ampullae lie parallel and medial to the seminal vesicles; at their lower ends each loses its thick muscle wall and joins with the outlet of the seminal vesicle to form the **ejaculatory duct**. Each ejaculatory duct passes obliquely through the prostate to open on the side of the urethral crest (Figs 5.57 and 5.58).

The **seminal vesicle** is a thin-walled, elongated sac, like a lobulated, blind-ending tube much folded on itself. The pair produce about 60% of the seminal fluid, and are applied to the base of the bladder above the prostate (Fig. 5.58). They are covered behind by the rectovesical fascia, and their tips are just covered by

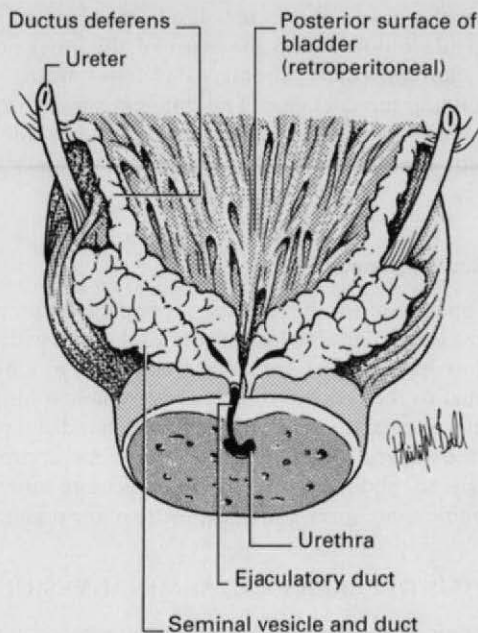


Fig. 5.58 Bladder and upper part of the prostate from behind. The ureter on each side enters the bladder wall above the tip of the seminal vesicle, with the ductus deferens medial to the vesicle.

the peritoneum of the rectovesical pouch. Each lies lateral to the ampulla of the ductus deferens of its own side, and at the lower end of the ampulla behind the prostate the duct of the seminal vesicle joins the ductus to form the ejaculatory duct.

Blood supplies. The artery to the ductus deferens is a branch of the superior vesical (or sometimes the inferior vesical) artery. It accompanies the ductus to the lower pole of the epididymis and anastomoses with the testicular artery (p. 306). The seminal vesicles are supplied by branches from the inferior vesical and middle rectal arteries.

Lymph drainage. Lymphatics accompany the blood vessels to the nearest iliac nodes.

Nerve supplies. The smooth muscle of the ductus and seminal vesicles receives fibres from the pelvic plexus. The sympathetic fibres run in the branch from the first lumbar ganglion and are motor; their division produces sterility, for the paralysed muscle cannot contract to expel the stored secretion and spermatozoa, i.e. there is no emission or ejaculation (p. 411).

Structure

The striking histological feature of the ductus deferens is the *thickness of the muscular wall* compared with the

small size of the lumen (p. 309); this alone should distinguish it from all other tubes. The mucous membrane is generally lined by pseudostratified epithelium with stereocilia which become lost near the termination of the ductus.

The muscle coat of the seminal vesicle is thinner than that of the ductus and consists only of two layers — inner circular and outer longitudinal. Although a single tube it is much convoluted and so appears in sections as a number of tubules, with mucosa that is very folded giving a glandular appearance. The epithelium is tall columnar or pseudostratified.

Development

The ductus deferens is a main derivative of the mesonephric duct (pp. 309 and 370), and at the back of the prostate a diverticulum from the duct forms the seminal vesicle.

PART 15

FEMALE INTERNAL GENITAL ORGANS AND URETHRA

UTERUS

This is a muscular organ whose function is to provide a nidus for the developing embryo. In the virginal state it is the shape of a flattened pear. Its size is about $8 \times 5 \times 3$ cm ($3 \times 2 \times 1$ in). It possesses a fundus, body and cervix. It receives the uterine tubes, and the cervix protrudes and opens into the vault of the vagina.

The **fundus** is the part above the entrance of the tubes (Fig. 5.59). It is convex and measures about 5 cm (2 in) from side to side and about 3 cm (1 in) thick. It possesses a serous coat of pelvic peritoneum which continues downwards over the front and back of the body (Fig. 5.61).

The **body** of the uterus tapers downwards from the fundus and is flattened anteroposteriorly. Each upper angle (cornu), at the junction of fundus and body, receives the uterine tubes. The body is enclosed by peritoneum which laterally becomes the broad ligament. The intestinal surface of the body faces upwards with coils of intestine lying upon it, while the vesical surface rests on the bladder with the peritoneum of the vesicouterine pouch intervening (Fig. 5.61). The cavity of the uterus occupies the body. A narrow slit in the virgin, it enlarges during pregnancy by growth of the uterine walls to accommodate the fetus. The lowest

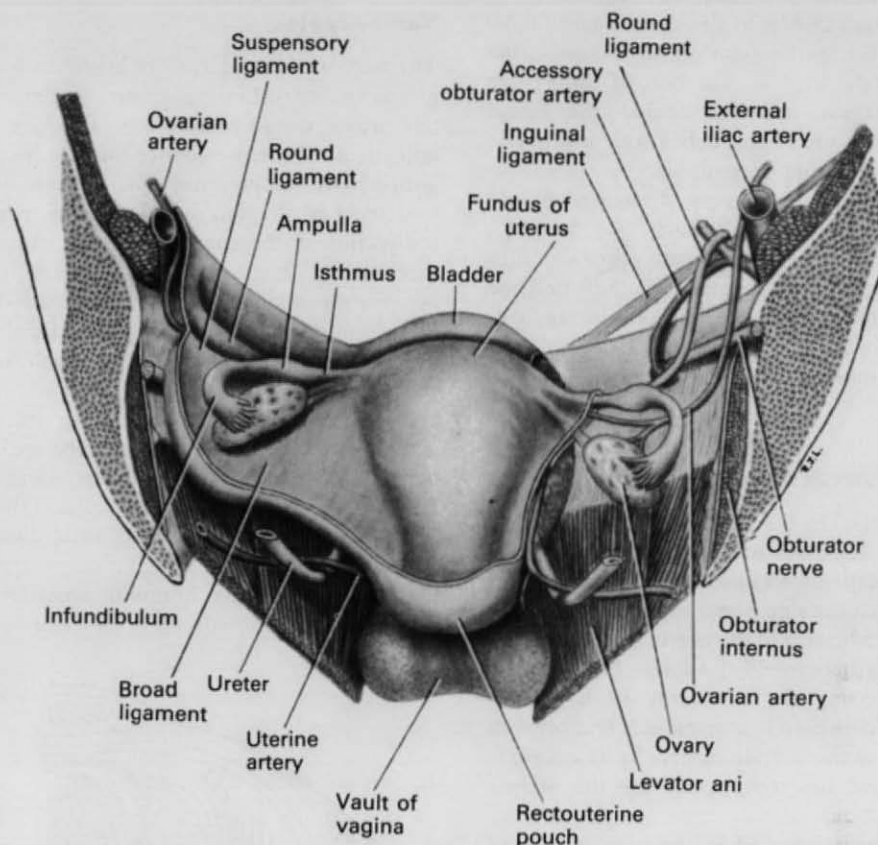


Fig. 5.59 Anterior half of a coronal section of the female pelvis, from behind. The broad ligament and parietal peritoneum have been removed on the right side.

half centimetre of the body which becomes continuous with the cervix is the isthmus, and forms what obstetricians call the 'lower uterine segment' at full term.

The **cervix** of the uterus tapers below the body and its lower end is clasped by the vault of the vagina, into which it protrudes (Fig. 5.61). It thus has vaginal (lower) and supravaginal (upper) parts, the latter like the body of the uterus having intestinal and vesical surfaces. The deep sulcus which surrounds the protruding cervix is the fornix of the vagina, and is deepest posteriorly. The intestinal surface is covered by peritoneum that continues from the body on to the upper part of the fornix, forming the anterior wall of the **rectouterine pouch** (of Douglas). The vesical surface has no peritoneal covering, being deep to the vesicouterine pouch and attached to the bladder above the trigone by rather dense connective tissue. The ureter, by lying first lateral to and then in front of the fornix, comes to pass about 1–2 cm from the cervix (Fig. 5.59). The body of the uterus is rarely exactly in

the midline; when deviated to one side the cervix becomes deflected to the opposite side, so one ureter may be closer to the cervix than the other.

The **canal of the cervix** is continuous with the cavity of the body at what is commonly called the internal os. The lower opening into the vagina is the external os; this is circular in the nulliparous but usually a transverse slit after childbirth, with anterior and posterior lips. The external os is normally on a level with the ischial spines.

UTERINE TUBES

Each tube is 10 cm long. The proximal 1 cm (*uterine part*, formerly called the intramural or interstitial part) is embedded in the uterine wall. Emerging from the cornu, the tube then lies in the upper edge of the broad ligament (Fig. 5.59), the peritoneal fold embracing it being the **mesosalpinx**. The part adjacent to the uterus (the *isthmus* of the tube) is straight and narrow,

but distally it becomes wider as the *ampulla* and finally ends as a trumpet-shaped expansion, the *infundibulum* or fimbriated end, with a number of finger-like processes. This open end lies behind the broad ligament adjacent to the lateral pelvic wall and ovary, whose liberated ova should drop into it.

The tube, formed of two layers of visceral muscle (inner circular and outer longitudinal, like the gut), is lined by a mucous membrane thrown into folds; they are sparse in the isthmus but become increasingly complicated as the ampulla is reached. The surface epithelium is a mixture of ciliated and non-ciliated columnar cells — an important identifying feature.

Blood supply of uterus and uterine tubes

The uterus is supplied by the uterine artery, a branch of the internal iliac. It passes medially across the pelvic floor in the base of the broad ligament, above the ureter (Fig. 5.59), to reach the side of the supravaginal part of the cervix. Giving a branch to the cervix and vagina, the vessel turns upwards between the layers of the broad ligament to run alongside the uterus as far as the entrance of the tube where it anastomoses end on with the tubal branch of the ovarian artery. In its course it freely gives off branches which penetrate the uterine walls.

The uterine tube is supplied by the tubal branch of the ovarian artery. The tubal artery runs below the tube, between the layers of the broad ligament, to anastomose with the uterine artery.

The veins of the uterus course below the artery at the lower edge of the broad ligament where they form a wide plexus across the pelvic floor. This communicates with the vesical and rectal plexuses and drains to the internal iliac veins. The tubal veins join the ovarian veins (p. 391).

Lymph drainage

The body and fundus of the uterus normally drain mainly to external iliac nodes, but it is also possible for lymph to reach the inguinal nodes via the round ligament and the inguinal canal. There is only scanty lymphatic drainage along the tube and ovarian vessels to aortic nodes. The cervix drains to external and internal iliac nodes by lymphatic channels that run respectively in front of or behind the ureter, and also to sacral nodes via the uterosacral ligaments. Note that while lymph from the body of the uterus may reach inguinal nodes, that from the cervix does not.

Nerve supply

The nerves of the uterus are branches from the pelvic plexus (p. 399). Little is known of motor pathways to this organ, whose muscle is so sensitive to hormonal influences. There is evidence that the (vasoconstrictor) sympathetic supply may also be motor to uterine muscle, but division of all uterine nerves or high transection of the spinal cord does not affect uterine contractility, even in labour. Sensory pathways are better understood although there are still discrepancies. Pain from the cervix is usually considered to be carried by the *pelvic splanchnic nerves*, although from the *upper* cervix it appears to run with *sympathetic nerves* as does pain from the body of the uterus (including labour pains). The cord segments concerned are T10–L1, and pain can be referred to the corresponding dermatomes. However, *presacral neurectomy* (cutting the hypogastric nerves from the superior hypogastric plexus) does not abolish labour pain, although it may improve dysmenorrhoea. The abolition of uterine sensation requires the

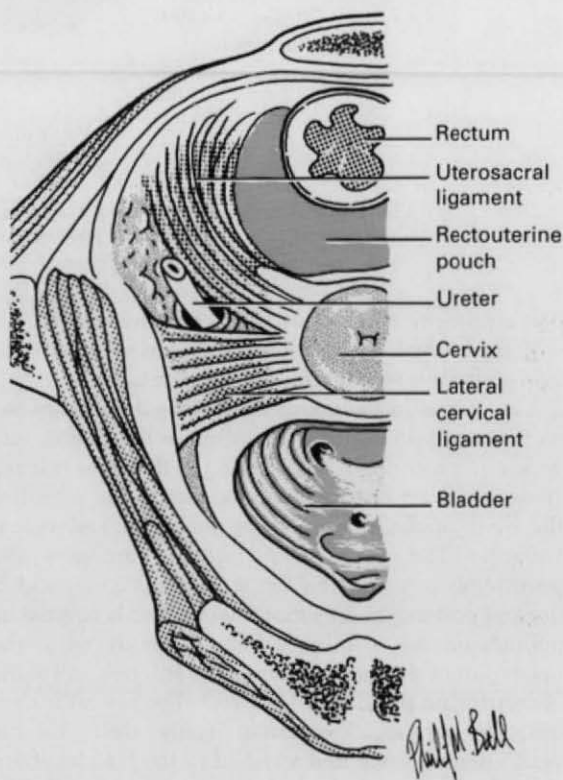


Fig. 5.60 Section of the middle and left part of the female pelvis, parallel with the pelvic brim and through the uterine cervix, viewed from above to show the condensations of tissue that form the uterosacral and lateral cervical ligaments.

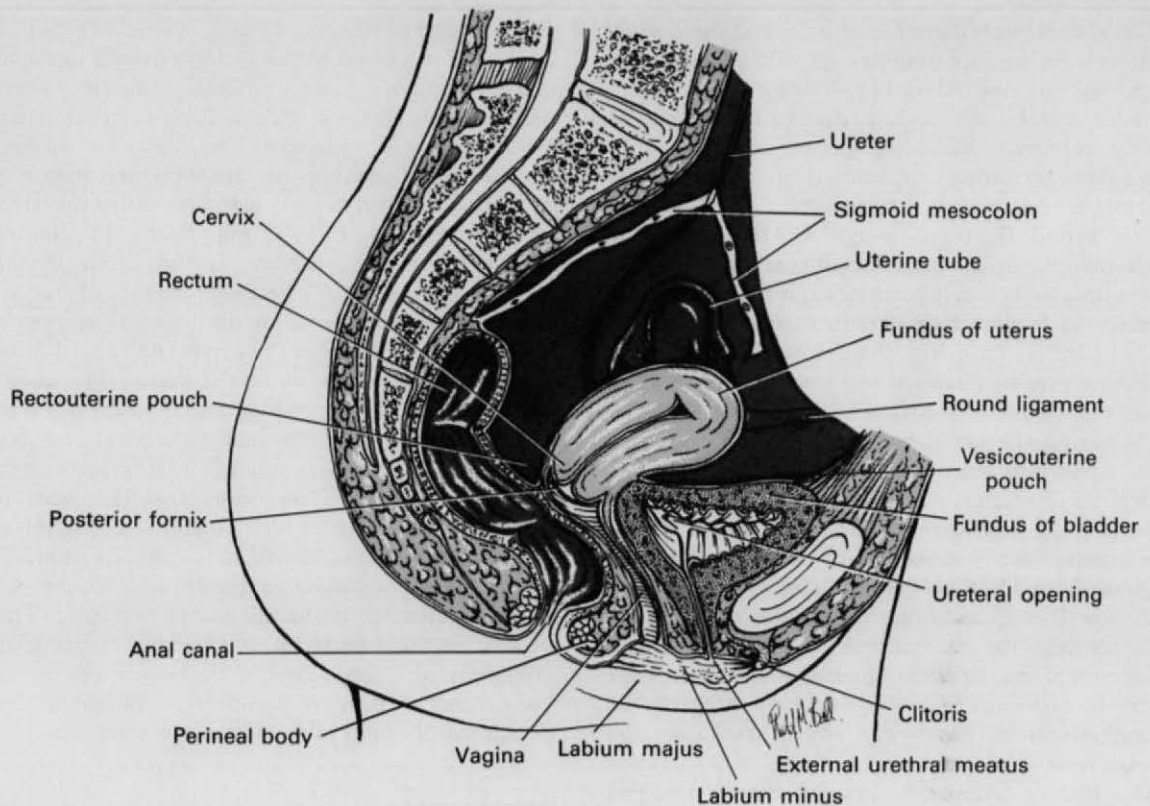


Fig. 5.61 Left half of the female pelvis with the attachment of the sigmoid mesocolon and the ureter entering the pelvis beneath its apex.

division of all nerves, or transection of the cord, above T10 level. As with most hollow viscera, distension causes pain, but both the cervix and body are relatively insensitive to cutting and burning; in contrast, the uterine tube is sensitive to touching and cutting.

Structure

The bulk of the uterus is smooth muscle, the **myometrium**, whose fibres are often described as being in three layers, but these are ill-defined. The outer muscle fibres tend to be longitudinal and expulsive in function, while many of those more deeply placed are circular and act as sphincters round the larger blood vessels, the openings of the uterine tubes and the internal os. The mucous membrane or **endometrium** has a lining of columnar epithelium which dips down into the endometrial stroma or lamina propria to form the *endometrial glands*. The thickness of course varies with the different stages of the menstrual cycle; at menstruation the bases of the glands remain to provide the source for the new epithelial covering. The mucosa of

the cervix does not take part in the cyclical changes and is not shed at menstruation; the surface cells are mucus-secreting and there are also mucous glands. Just inside the external os the epithelium changes to the stratified squamous variety of the vagina. The outer or serous covering of the uterus is the peritoneum.

Supports

The normal position of the uterus is one of anteversion and slight antelexion, i.e. the fundus and upper part of the body are bent forward in relation to the long axis of the cervix (angle of *antelexion*), while the organ thus flexed leans forward as a whole from the vagina (angle of *anteversion*). As many as 20% of nulliparous females may have a retroverted uterus, without any ill effects. The most fixed part of the uterus is the cervix, because of its attachment to the back of the bladder and to the vaginal fornix, and a number of structures help directly or indirectly to maintain the normal position. These include the pelvic diaphragm, condensations of pelvic fascia and to a lesser extent some peritoneal attachments.

The *pubovaginalis* part of levator ani and the *perineal body* with its inserted muscles (p. 405) support the vagina and so assist indirectly in holding the cervix up. If these muscles are unduly stretched or damaged during childbirth the posterior vaginal wall sinks downwards (prolapses), and this is often followed by prolapse or retroversion of the uterus.

The **broad ligament** is not strictly speaking a ligament in the usual sense, since it consists of no more than a lax double fold of peritoneum lying lateral to the uterus, and it plays little part in uterine support. Its medial edge is attached to the side wall of the uterus and flows over its intestinal and vesical surfaces as its serous coat. The lateral edge is attached to the side wall of the pelvis, whence the two layers of its inferior edge or base pass forwards and backwards to line the pelvic cavity; the posterior layer most importantly has the *ureter adhering underneath it*. The line of lateral attachment crosses the obturator nerve, superior vesical or obliterated umbilical vessels, and the obturator artery and vein. The upper border of the broad ligament is free, forming the mesosalpinx and containing the uterine tube, and the lateral quarter of this upper edge forms the *suspensory ligament of the ovary* (formerly the infundibulopelvic ligament), which contains the ovarian vessels and lymphatics (p. 391).

The anterior layer of the broad ligament is bulged forwards by the round ligament of the uterus just below the uterine tube. The posterior layer bulges backwards as the *mesovarium*, suspending the ovary. Between the two layers is a mass of areolar tissue, the parametrium, in which lie the uterine and ovarian vessels and lymphatics, the round ligament of the uterus, the ligament of the ovary, and vestigial remnants of mesonephric tubules (the epoöphoron and paroöphoron, (p. 392).

The **round ligament of the uterus** extends from the junction of the uterus and tube to the deep inguinal ring. It lies in the anterior layer of the broad ligament below the uterine tube; no special name is given to the peritoneal fold that contains it. It is continuous with the ligament of the ovary (p. 391), the two ligaments in continuity representing the gubernaculum, the counterpart of the gubernaculum of the testis. The round ligament passes through the inguinal canal and is attached at its distal extremity to the fibrofatty tissue of the labium majus of the vulva. It is supplied by a branch of the ovarian artery in the broad ligament and by a branch from the inferior epigastric artery in the inguinal canal. It consists largely of visceral muscle, and it acts to hold the uterus forwards in anteversion and anteversion, especially when forces tend to push the uterus backwards (e.g. distension of the bladder, gravity during recumbency).

The extraperitoneal tissue (pelvic fascia) is condensed in certain places to form named ligaments which contain some visceral muscle fibres. Unfortunately they are often difficult to appreciate in dissecting room specimens because they become atrophic in old age, but they are supremely important for uterine stability, in particular those called the lateral and uterosacral ligaments (Fig. 5.60). The **lateral ligament**, otherwise known as the *lateral cervical, cardinal or Mackenrodt's ligament*, consists of thickenings of connective tissue in the base of each broad ligament, extending from the cervix and vaginal fornix laterally to the side wall of the pelvis. The ureter, uterine artery and inferior hypogastric plexus lie on the upper surface of this tissue and the cervical branch of the uterine artery passes through it. It imparts lateral stability to the cervix. The **uterosacral ligaments** are similar condensations of very variable size that extend backwards from the cervix below the peritoneum, embracing the rectouterine pouch and rectum and becoming attached to the fascia over piriformis. They are best palpated on rectal (not vaginal) examination. They keep the cervix braced backwards against the forward pull of the round ligaments on the fundus and so maintain the body of the uterus in anteversion.

Development

The paramesonephric (Müllerian) ducts (p. 309) fuse at their caudal ends to make the uterus and upper part of the vagina. Their cranial ends persist as the uterine tubes. Incomplete fusion results in a median septum in the uterus or in a bicornuate uterus. The latter is the usual state in most mammals, where the multiple pregnancies occupy both uterine horns.

Surgical approach

For total hysterectomy (removal of body and cervix) the broad, round and ovarian ligaments and the uterine tubes are divided on each side near the uterus. The peritoneum of the vesicouterine pouch is incised transversely so that the bladder and lower ends of the ureters can be pulled away from the body of the uterus, cervix and fornix, and the uterine arteries are divided. The uterosacral ligaments are transected and the anterior and posterior vaginal walls are cut across below the cervix. For subtotal hysterectomy the cervix is cut across at the level of the lateral ligaments without opening into the vagina.

In any pelvic operation, the ureters are the structures at greatest risk, especially when disease has distorted the normal anatomy, described on page 383.

OVARY

The **ovary** is ovoid in shape, smaller than the testis. It is firm to the touch, being composed of rather dense fibrous tissue in which the ova are embedded. It projects into the pelvic cavity, attached to the posterior leaf of the broad ligament (Fig. 5.59) by a double fold of peritoneum, the **mesovarium**. The **mesovarium** is attached equatorially around the ovary, but does not invest the surface of the gland, which is covered with low columnar epithelium. The ovary often lies flush within the posterior leaf of the broad ligament, in which case there is no mesovarium, but traction on the ovary will pull up the peritoneum into a temporary 'mesovarium'.

The ovary lies on the peritoneum of the side wall of the pelvis, in the shallow ovarian fossa in the angle between the internal and external iliac vessels, on the obturator nerve. A diseased ovary may therefore cause pain along the cutaneous distribution of this nerve (the inner side of the thigh down to the knee); the parietal peritoneum against which the ovary lies is supplied by it. The obturator internus muscle and its fascia separate the ovary from the thinnest part of the hip bone, the concavity of the acetabulum. The ovary in its normal position can just be reached through the vagina by the tip of the examining finger. It is overlaid by the coils of sigmoid colon and ileum that occupy the rectouterine pouch of Douglas.

The ovary usually lies with its long axis oblique, its tubal extremity uppermost and medial. It is attached at its uterine extremity to the upper angle of the uterus by the **ligament of the ovary**. This is a mass of smooth muscle and fibrous tissue lying between the two layers of the broad ligament, and continuous with the round ligament, the whole being the remnant of the gubernaculum.

Blood supply

The ovary is supplied by the ovarian artery, a branch of the abdominal aorta just below the renal artery. The vessel runs down behind the peritoneum of the infracolic compartment and the colic vessels, crossing the ureter obliquely, on the psoas muscle. It crosses the brim of the pelvis and enters the *suspensory ligament* (formerly the infundibulopelvic ligament) at the lateral extremity of the broad ligament. It gives off a branch to the uterine tube which runs medially between the layers of the broad ligament and anastomoses with the uterine artery, and it ends by entering the ovary (Fig. 5.59).

The ovarian veins form a plexus in the mesovarium and the suspensory ligament (the *pampiniform plexus*

like the testis). The plexus drains into a pair of ovarian veins which accompany the ovarian artery. They usually combine as a single trunk before their termination. That on the right joins the inferior vena cava, that on the left the left renal vein.

Lymph drainage

The lymphatics of the ovary drain to para-aortic nodes alongside the origin of the ovarian artery, just above the level of the umbilicus (L2). Clinical observation shows that it is also possible for lymph to reach inguinal nodes via the round ligament and the inguinal canal, and to reach the opposite ovary by passing across the fundus of the uterus.

Nerve supply

Sympathetic (vasoconstrictor) fibres reach the ovary from the aortic plexus along its blood vessels; the preganglionic cell bodies are in T10 and 11 segments of the cord. Some parasympathetic fibres may reach the ovary from the inferior hypogastric plexus via the uterine artery and are presumably vasodilator. Autonomic fibres do not reach the ovarian follicles; an intact nerve supply is not required for ovulation. Sensory fibres accompany the sympathetic nerves, so that ovarian pain may be periumbilical, like appendicular pain.

Structure

The ovary consists of a fibrous **stroma** covered by a layer of cubical cells, the **superficial epithelium**, that was originally but mistakenly called germinal epithelium; it has nothing to do with the formation of the primitive germ cells (*oogonia*) which are derived in the early embryo from endodermal cells of the hindgut (yolk sac) that migrate laterally into the developing gonad. By mitosis and growth the oogonia become *primary oocytes* surrounded by granulosa cells derived from the stroma. A primary oocyte with a single layer of granulosa cells is a *primary follicle*; when the granulosa cells proliferate to form more than one layer, the primary follicle becomes a *secondary follicle*. In a 5-month fetus there are about 6 million follicles, but many degenerate and by birth there are 1 million, reduced to about 40 000 by puberty. Each month during reproductive life a follicle grows and accumulates fluid (liquor folliculi), to become an *ovarian (Graafian) follicle*. The stromal cells surrounding the follicle form the theca. Before ovulation the primary oocyte undergoes *meiosis* (halving the chromosome

number) forming a *secondary oocyte*. It is this cell, commonly called the *ovum*, that is discharged at ovulation. The liquor folliculi escapes and haemorrhage occurs into the collapsed follicle. The granulosa cells and some of the thecal cells now develop into a *corpus luteum*. This persists for 1 week if pregnancy does not occur, or for 9 months if it does. At the end of either time it atrophies and becomes replaced by a fibrous scar, the *corpus albicans*.

Since only about 400 ova can be shed in the course of reproductive life, most oocytes and follicles are destined never to reach maturity, and they can undergo degeneration at any stage of their development, becoming known as *atretic follicles*.

Development

The ovary develops from the *paramesonephric ridge* of the intermediate cell mass (p. 36) in the same way as the testis. Its site of origin lies in the peritoneum of the posterior abdominal wall. It descends, preceded by the gubernaculum. The *gubernaculum* proceeds through the inguinal canal, as in the male, and becomes attached to the labium majus. The ovary does not follow its gubernaculum so far, and its descent is arrested in the pelvis. The gubernaculum persists as the *ligament of the ovary* and the *round ligament of the uterus*. The ovary is supplied by its own branch from the dorsal aorta and drains into the subcardinal vein. As with the testis, artery and vein persist, becoming merely elongated as the gonad descends to its adult position.

The *mesonephric tubules* and *mesonephric duct* normally disappear in the female. Should they persist their remnants are to be found between the layers of the broad ligament. The *epoöphoron* consists of a number of *tubules* joining at right angles a persistent part of the mesonephric duct. It lies in the *mesosalpinx* between ovary and tube. The *mesonephric duct* may persist as a tube (*duct of Gaertner*) opening into the lateral fornix of the vagina or even at the vestibule of the vulva alongside the vaginal orifice. The *paroöphoron* lies nearer the base of the broad ligament. It consists of a number of minute *tubules*, blind at each end, the homologue of the paradidymis in the male (p. 309). Distension of such a tubule produces a parovarian cyst, characterized by its thin wall and crystal-clear fluid content.

VAGINA

The tubular *vagina* lies in approximately the same direction as the pelvic brim. For much of its total length (about 10 cm) the anterior and posterior walls are in opposition, i.e. the lumen is transverse, but the *vaginal*

orifice (introitus) is an anteroposterior slit. The vagina extends from the uterine cervix to the labia minora of the pudendal cleft of the vulva; its lower end is thus in the perineum. It lies in front of the rectum, anal canal and perineal body, and behind the bladder and urethra (Fig. 5.61). The upper end is slightly expanded and receives the uterine cervix which projects into it, forming round the margin of the cervix a circular groove or *vaginal fornix*, which for descriptive convenience is usually subdivided into anterior, posterior and lateral fornices. The uppermost parts of the vagina are the posterior and lateral fornices. The posterior fornix is covered by peritoneum of the front of the rectouterine pouch (of Douglas); this is the only part of the vagina to have a peritoneal covering. The ureter is first adjacent to the lateral fornix and then passes over the front of the anterior fornix to enter the bladder.

Below the cervix the anterior wall of the vagina is in contact with the base (posterior surface) of the bladder, and below the bladder the *urethra is embedded in the vaginal wall*. The vagina passes down between the pubovaginalis parts of levator ani, through the urogenital diaphragm and perineal membrane (i.e. through the deep perineal space) into the superficial perineal space to become the *vestibule* of the vagina. Here it may show internally the remains of the hymen, and the duct of the greater vestibular (Bartholin's) gland opens on each side just below the hymen in the posterolateral wall. Lateral to the vestibule is the bulb of the vestibule covered by the bulbospongiosus muscle and with the greater vestibular gland under cover of the posterior end of the bulb. The urethra opens immediately in front of the vaginal orifice, which is guarded below by the labia minora and the minute openings of the lesser vestibular glands are behind the urethral orifice (p. 412).

Blood supply

The vaginal branch of the internal iliac artery is an obvious supply, but other sources include the uterine, inferior vesical and middle rectal vessels, whose branches all make good anastomotic connexions on the vaginal wall. This variety of branches may help to keep the organ adequately supplied during the extreme dilatation of childbirth. Veins join the plexuses on the pelvic floor to drain into the internal iliac vein.

Lymph drainage

The lymphatics of the vagina, like those of the cervix, drain to external and internal iliac and sacral nodes, but the lowest part (below the hymen level) drains like other perineal structures to superficial inguinal nodes.

Nerve supply

The lower end of the vagina receives sensory fibres from the perineal and posterior labial branches of the pudendal nerve, and (with the anterior part of the vulva) from the ilioinguinal nerve. Sympathetic fibres from the hypogastric plexuses supply blood vessels and the smooth muscle of the vaginal wall. The upper vagina is said to be sensitive only to stretch, the afferent fibres running with sympathetic nerves.

Structure

The vagina has a muscular layer of smooth muscle lined internally by mucous membrane and covered externally by fibrous tissue continuous with the pelvic fascia, except at the posterior fornix which has a peritoneal covering. The smooth muscle fibres are arranged mainly longitudinally, and at the lower end blend with the skeletal fibres of pubovaginalis and bulbospongiosus. The mucous membrane consists of stratified squamous non-keratinizing epithelium overlying a connective tissue lamina propria; there is no muscularis mucosae and no glands — features that distinguish a histological section from that of oesophagus, whose epithelium is exactly similar.

Vaginal examination

Using the index and middle fingers, the uterine cervix can be felt in the upper vagina, with the bladder, urethra and pubic symphysis at the front. The rectum is behind, with the rectouterine pouch just in front of it (a possible site for malignant deposits, which may have gravitated to this lowest part of the peritoneal cavity). At the sides the ovary and uterine tube may be palpated (and very rarely a stone in the lower ureter).

Development

Most of the vagina is formed (like the uterus, p. 392) from the distal part of the fused *paramesonephric* (Müllerian) ducts (p. 36), but the lower part is derived from the *urogenital sinus* (p. 44), whose epithelium appears to replace that derived from the ducts. The labia minora that bound the vaginal orifice are formed from the urogenital folds (the labia majora are from the more laterally-placed labioscrotal swellings).

FEMALE URETHRA

The **female urethra** is about 4 cm long, passing from the neck of the bladder at the lower angle of the trigone

to the external urethral meatus (Fig. 5.61), which is in the vestibule of the vagina (p. 392) in front of the vaginal orifice and 2.5 cm behind the clitoris. The urethra is not simply in front of the vagina throughout its short course, but all except its uppermost end is *embedded within the vaginal wall*. As it leaves the bladder, fibres of the pubovaginalis part of levator ani lie adjacent to it, and although these periurethral fibres are not connected to the urethra they play some part in compressing it. There is no internal urethral sphincter in the female (p. 383).

With the urethra being such a short straight tube, catheterization in the female is simple compared with the male, but it must be remembered that in the later stages of pregnancy the urethra may be considerably stretched so that the catheter may have to be passed for more than twice the normal distance. The pubic symphysis lies in front; the full-term fetal head can compress the urethra against it, and the vaginal stretching during birth can increase the urethral length to 10 cm.

Blood supply

The upper part of the urethra is supplied by the inferior vesical and uterine arteries, with the lower end receiving contributions from the perineal branch of the internal pudendal artery. Veins drain to the vesical plexus and the internal pudendal vein.

Lymph drainage

Lymph vessels pass mainly to internal iliac nodes but some reach the external iliac group.

Nerve supply

Fibres reach the urethra from the inferior hypogastric plexuses and from the perineal nerve.

Structure

The mucous membrane is lined by transitional epithelium, and there are a few mucous glands in the wall. The largest of these, the *paraurethral glands* (of Skene) open by a single duct on each side just inside the external meatus, and are the female homologue of the prostate. As in the male, *superficial trigonal muscle* fibres extend into the upper urethra but their function is not clear. Outside the mucous membrane is a *longitudinal layer* of visceral muscle stretching from the bladder neck to the external meatus. Outside the visceral muscle is the **external urethral sphincter** (sphincter urethrae) of circular skeletal muscle fibres. The

sphincter is thickest near the middle of the urethra, and thicker in front than at the sides or back (where there are very few muscle fibres). As in the male it consists of small fibres of the slow twitch variety; they are attached to the pubic rami and perineal body (p. 405), and are supplied by the perineal nerve.

Development

The female urethra is developed from the vesicourethral part of the cloaca (p. 43), and corresponds to the part of the male prostatic urethra that is proximal to the openings of the prostatic utricle and ejaculatory ducts (p. 309).

PART 16

PELVIC PERITONEUM, VESSELS AND NERVES

PELVIC PERITONEUM

The pelvic peritoneum is draped over the pelvic viscera and invests them in part with a serous coat. Between the viscera it hangs in dependent folds or pouches. These differ somewhat in the two sexes. As elsewhere, the visceral layer has no nerve supply. The parietal peritoneum, on the pelvic walls, is supplied by the obturator nerve (L3).

Pelvic peritoneum in the male

From the margin of the pelvic brim the peritoneum descends across the pelvic walls to line the cavity, but nowhere does it descend far enough to reach the pelvic floor. Anteriorly in the midline it descends but little below the upper margin of the pubic symphysis, and then only when the bladder is empty. It passes from the lower part of the anterior abdominal wall and is reflected in a shallow fold to the upper surface of the bladder, where it is densely adherent. The fold roofs in the **retropubic space** (of Retzius). If the bladder rises in distension above the symphysis this fold of peritoneum is stripped upwards from the anterior abdominal wall. A trocar can then be introduced through the anterior abdominal wall into the bladder below the fold; in this way extraperitoneal drainage of the bladder may be carried out as a relief measure in cases of urethral obstruction. From the back of the bladder the peritoneum descends in a fold before ascending over the rectum and the hollow of the

sacrum. This fold is the **rectovesical pouch**. The retroperitoneal tissue, stretching from the depth of the pouch to the perineal body and passing between the bladder and prostate in front and the rectum behind, is the **rectovesical fascia** (of Denonvilliers). In the past this fascia has been considered to represent the fused lower end of the embryonic peritoneal pouch which extended to a lower level than in the adult, but this view may not be correct.

The midline visceral peritoneum, including its folds, passes laterally in a continuous sheet to the side wall of the pelvis and becomes continuous with the parietal peritoneum of the abdominal cavity at the pelvic brim.

The pelvic peritoneal cavity is occupied by coils of the sigmoid colon and the lower part of the ileum, which lie in front of the rectum and above the bladder.

Pelvic peritoneum in the female

The arrangement of the peritoneum is similar to that in the male, the only difference being the presence of the uterus and the broad ligaments. From the back of the bladder the peritoneum ascends over the front of the uterus, making the **vesicouterine pouch** between the two viscera. The visceral peritoneum of the uterus is firmly attached to the back of that organ *and to the posterior fornix* of the vagina, whence it is reflected up over the rectum and sacrum. This deep pouch of peritoneum is the **rectouterine pouch** (of Douglas) (Fig. 5.61). It is opened by incision through the posterior fornix, and this method is employed in draining an intraperitoneal pelvic abscess in the female.

Each side of the uterus is attached to the side wall of the pelvis by the broad ligament, which extends down towards the pelvic floor (p. 390).

PELVIC VESSELS

The pelvic walls and viscera are supplied by branches of the internal iliac artery and drain into tributaries of the internal iliac veins. Just as the commencement of the inferior vena cava lies to the right of the aorta and dorsal to the right common iliac artery, so the internal iliac veins tend to lie to the right and dorsal to their companion arteries. Arteries and veins lie within the parietal pelvic fascia and only their branches that pass out of the pelvis (except the obturator vessels) need to pierce this membranous structure.

Internal iliac artery

The common iliac artery bifurcates at the pelvic brim opposite the sacroiliac joint (Fig. 5.62). From this point

behind the obturator nerve, running laterally deep to the psoas muscle. Its *lumbar branch* is really the fifth lumbar segmental artery. It passes laterally to supply psoas and quadratus lumborum and, by its posterior branch, erector spinae. This vessel gives a spinal branch into the foramen between L5 vertebra and the sacrum.

The *iliac branch* supplies the iliac fossa, i.e. the iliacus muscle and the iliac bone. It extends to the anastomosis around the anterior superior iliac spine (deep and superficial circumflex iliac arteries, ascending branch of the lateral circumflex femoral artery and the upper branch of the deep division of the superior gluteal artery).

The **lateral sacral artery** runs down lateral to the anterior sacral foramina, i.e. in front of the roots of the sacral plexus. In the pelvis it supplies the roots (Fig. 5.55) and piriformis. *Spinal branches* enter the anterior sacral foramina, supply the spinal meninges and the roots of the spinal nerves and pass through the posterior sacral foramina to reach the muscles over the back of the sacrum. The artery takes over the segmental supply from the lumbar arteries and, as might be expected, it is often multiple; the commonest variant is for an upper sacral artery to supply the first two sacral segments and a lower sacral artery to supply the remaining segments in the pelvis (Fig. 5.62).

The **superior gluteal artery**, the largest of all the branches of the internal iliac (Figs 5.55 and 5.62), passes backwards by piercing the pelvic fascia usually between the lumbosacral trunk and S1 nerve, and leaves the pelvis through the greater sciatic foramen above the upper border of piriformis. Its course and distribution in the buttock are considered on page 164.

Branches of the anterior division

The **superior vesical artery**, is usually the highest anterior branch of the internal iliac (Fig. 5.55), and is the persistent patent proximal part of the fetal umbilical artery. The distal part becomes obliterated to form the medial umbilical ligament (p. 313) which thus appears as the direct continuation of the vesical vessel. The superior vesical artery runs first along the side wall of the pelvis and then turns medially to reach the upper part of the bladder, often raising a fold of peritoneum from the pelvic wall. Apart from the bladder it supplies the adjacent ureter and ductus deferens.

The **inferior vesical artery**, as might be expected, arises much lower than the superior and runs medially across the pelvic floor to supply the trigone and lower part of the bladder, the ureter, ductus deferens and seminal vesicle. It also usually gives rise to the *prostatic artery*.

The **middle rectal artery** arises with or near the inferior vesical, but may be absent, especially in the female where it may be said to be replaced by the uterine and vaginal branches. It runs towards the lower rectal wall, breaking into a leash of branches before entering it, and in the male it may give off the prostatic artery if that has not arisen from the inferior vesical.

The **uterine artery** crosses the pelvis in the base of the broad ligament, passing superficial to the ureter. At the cervix it turns upwards closely applied to the muscle thereof and runs alongside the uterus in the broad ligament. At the entrance of the uterine tube it anastomoses end on with the tubal branch of the ovarian artery.

The **vaginal artery**, often a branch of the uterine, supplies the very vascular walls of the upper part of the vagina.

The **obturator artery** passes along the side wall of the pelvis below the nerve (Fig. 5.62) to enter the obturator foramen with the artery and vein and pass into the thigh. The artery gives off a small branch to the priosteum of the back of the pubis, and this vessel anastomoses with the pubic branch of the inferior epigastric artery. In about 50% of cases this anastomotic connexion opens up to become the *accessory* or *abnormal obturator artery*, replacing the normal branch from the internal iliac. In its passage from the inferior epigastric to the obturator foramen, it usually passes on the *lateral* side of the femoral ring, i.e. adjacent to the external iliac vein (Fig. 5.10). When it lies at the *medial* side of the ring, alongside the edge of the lacunar ligament (Fig. 5.11), it is vulnerable to injury or division if the ligament has to be incised to release a strangulated femoral hernia.

The **internal pudendal artery** lies in front of the inferior gluteal (Fig. 5.62), pierces the parietal pelvic fascia and passes out of the pelvis through the greater sciatic foramen below piriformis. It is distributed in the perineum to the anal region and the external genitalia (p. 410).

The **inferior gluteal artery** runs backwards through the parietal pelvic fascia, passes below S1 nerve root (or sometimes S2; Fig. 5.62) and leaves the pelvis through the greater sciatic foramen below piriformis, to continue its course in the buttock (p. 164).

Pelvic veins

In demonstration and examination specimens of the pelvis, the profuse veins of the pelvic viscera and pelvic walls that accompany the arteries are usually removed; only surgeons who operate in the pelvis appreciate how many there are!

The **internal iliac vein**, a wide vessel about 3 cm long, begins above the greater sciatic notch by the confluence of gluteal veins with others that accompany branches of the internal iliac arteries. It passes upwards and forwards out of the pelvis, above and behind its artery, on to the medial surface of *psaos major*, where it joins the external iliac vein to form the common iliac. Apart from tributaries that correspond to arteries, the vein receives the *uterine* or *vesicoprostatic venous plexuses*, and the *rectal venous plexuses* (which also communicate with the portal system by the inferior mesenteric vein). By the *lateral sacral veins* it communicates with the vertebral venous plexuses. There are no valves in pelvic veins. Sudden increase in pelvic pressure (as in coughing) may be momentarily more than the inferior vena cava can accommodate, and this drives blood backwards up the internal vertebral plexus, into posterior intercostal veins and by azygos veins into the superior vena cava, bypassing the diaphragm. It is conceivable that emboli from disease of the pelvic viscera can find their way by occasional reflux blood flow into the vertebrae. In this way secondary carcinomatous deposits may appear in the vertebrae from primary growths in any of the pelvic viscera.

PELVIC NERVES

The obturator nerve passes along the lateral wall of the pelvis to the obturator foramen, but other nerves of the pelvis are related to the posterior wall. These include the sacral plexus and its branches within the pelvis, the sacral part of the sympathetic trunk, the inferior hypogastric (pelvic) plexuses and the pelvic splanchnic nerves (parasympathetic, *nervi erigentes*).

The **obturator nerve** is a branch of the lumbar plexus formed within the substance of *psaos major* from the anterior divisions of the second, third and fourth lumbar nerves (anterior rami). It is the nerve of the adductor compartment of the thigh, which it reaches by piercing the medial border of *psaos* and passing straight along the side wall of the pelvis to the obturator foramen. It crosses the pelvic brim medial to the sacroiliac joint (i.e. on the ala of the sacrum) and runs forward between the internal iliac vessels and the fascia on the obturator internus muscle. It appears in the angle between the internal and external iliac vessels, in which part of its course it is separated from the normally situated ovary only by the parietal peritoneum lining the pelvic wall. Pain from the ovary may be referred along the nerve to the skin on the medial side of the thigh. This may be less an irritation of the main nerve trunk than irritation or inflammation of the

parietal peritoneum, which is here supplied by the obturator nerve.

The obturator artery and vein converge to the obturator foramen, in which the nerve lies highest, against the pubic bone (Fig. 5.62) with the artery and vein beneath it. The nerve divides while in the foramen into *anterior* and *posterior divisions*; the former passes anterior to the upper border of obturator externus, while the posterior division, first giving off a branch to supply the obturator externus, pierces the muscle. The distribution in the thigh is considered on page 160.

The **accessory obturator nerve** is incorrectly named. Its only characteristic in common with the obturator nerve is that it leaves the medial border of *psaos*. Its more important bony relation is shared with the femoral nerve; like the femoral nerve it passes over, not under, the pubic ramus and, like the femoral nerve, it is derived from *posterior* and not *anterior* divisions of the anterior rami of L3 and 4 nerves. It should have been named the 'accessory femoral' nerve. It supplies pectineus but is present in only one-third of individuals.

SACRAL PLEXUS

Not all the lumbar nerves are used up in the formation of the lumbar plexus. Much of L4 and all of L5 anterior rami enter the sacral plexus. After L4 has given off its branches to the lumbar plexus it emerges from the medial border of *psaos* and joins the anterior ramus of L5 to form the **lumbosacral trunk**. This large nerve passes over the ala of the sacrum and crosses the pelvic brim, separated from the obturator nerve by the ilio-lumbar artery and veins. It descends to join the anterior rami of the upper four sacral nerves in the formation of the sacral plexus (Figs 5.55 and 5.71).

The **sacral plexus** is a broad triangular structure formed by the junction of the nerves lateral to the anterior sacral foramina (Fig. 5.55). It rests upon piriformis and is covered anteriorly by the strong membrane of parietal pelvic fascia which invests that muscle. Anterior to the fascia the lateral sacral arteries and veins lie in front of the sacral nerves. At a higher level the common iliac vessels lie over the lumbosacral trunk. S1 often separates the superior and inferior gluteal arteries, although the inferior gluteal may pass backwards between S2 and 3 instead of S1 and 2. The ureter, in front of the internal iliac vessels lies well anterior to the upper part of the plexus and in front of all are the parietal pelvic peritoneum and pelvic viscera.

The sacral nerves give off certain branches and then divide, as does the lumbosacral trunk, into anterior and posterior divisions which thereupon branch and reunite to form the nerves for the supply of flexor and extensor

compartments of the lower limb. The branches of the sacral plexus will be considered under these three headings. (A summary of their distribution is given on p. 416.)

Branches from the sacral nerves

These are six, three from behind and three from in front of the anterior rami. They are: twigs to piriformis (S1, 2), the perforating cutaneous nerve (S2, 3) and the posterior femoral cutaneous nerve (S2, 3) branching from behind, and the pelvic splanchnic nerves (S2, 3), the pudendal nerve (S2, 3, 4) and the perineal branch of S4 from in front.

The **piriformis** is supplied by separate twigs which pass backwards from S1 and 2.

The **perforating cutaneous nerve** arises from the posterior surfaces of S2 and 3. It pierces the sacrotuberous ligament and for a few millimetres is at the posterior edge of the ischioanal fossa before piercing or passing over the lower border of gluteus maximus. It supplies the skin of the buttock over the area where the two buttocks are just losing contact.

The **posterior femoral cutaneous nerve** is formed by branches that pass backwards from S2 and 3, with a small contribution from S1. The nerve passes laterally to leave the lower border of piriformis behind the sciatic nerve, which separates it from the ischium. It thus enters the buttock (p. 165).

The parasympathetic **pelvic splanchnic nerves** (*nervi erigentes*) arise by several rootlets from the anterior surfaces of S2 and 3 (or 3 and 4). They pass forward into the inferior hypogastric plexuses where they mix with the sympathetic nerves and are distributed to pelvic viscera and the distal colon (see below). The old term *nervi erigentes* is correct but incomplete; the nerves cause erection but much more (p. 399).

The **pudendal nerve** arises from the anterior surfaces of S2, 3 and 4 nerves. The three twigs unite to form a nerve which passes back between piriformis and coccygeus (Figs 5.55 and 3.16), medial to the pudendal vessels. In the buttock it appears between piriformis and the sacrospinous ligament, and curls around the latter to run forward into the ischioanal fossa (p. 404).

The **perineal branch of S4** (probably accompanied by a similar branch from S3) runs forwards on coccygeus and enters the perineum by passing between that muscle and the iliococcygeus part of levator ani. It supplies these muscles, including the puborectalis part of levator ani, and continues through the ischioanal fossa to supply the perianal skin. It does not supply the external anal sphincter (p. 376).

Branches from the anterior divisions

These nerves are destined for the flexor compartment of the lower limb. They are the tibial part of the sciatic nerve and the nerves to obturator internus and quadratus femoris (Fig. 3.16, p. 162).

The **tibial part of the sciatic nerve** is a big branch formed by union of branches from all five anterior divisions (L4, 5, S1, 2, 3). It usually joins the extensor compartment nerve (*common peroneal, common fibular*) in the pelvis and the sciatic nerve so formed leaves the pelvis below the lower border of piriformis lying on the ischium in the greater sciatic notch, lateral to the ischial spine. Its course in the buttock is considered on page 165.

The **nerve to obturator internus** (L5, S1, 2) also supplies the superior gemellus. It leaves the pelvis, lateral to the pudendal vessels, below the piriformis (p. 165).

The **nerve to quadratus femoris** (L4, 5, S1) also supplies the inferior gemellus and the hip joint. It leaves the pelvis in front of the sciatic nerve, which holds it down on the ischium (p. 165).

Branches from the posterior divisions

These are the nerves of the extensor compartment of the lower limb. They are the common peroneal (fibular) part of the sciatic nerve and the superior and inferior gluteal nerves (Fig. 3.16).

The **common peroneal (fibular) part of the sciatic nerve** is formed by union of branches from the posterior divisions of L4, 5, S1, 2 (there is no S3 in the extensor compartment). It usually joins the tibial part to form a combined nerve (p. 165), but not infrequently it fails to do so. In these cases the common peroneal part pierces the lower border of piriformis.

The **superior gluteal nerve** is formed from the posterior divisions of L4, 5 and S1. It passes out of the pelvis above the piriformis muscle (p. 164).

The **inferior gluteal nerve** is formed from the posterior divisions of L5 and S1 and 2. It passes below the lower border of piriformis into the buttock (p. 164).

The **coccygeal plexus** consists of a minor mingling of a branch from S4 with S5 and the coccygeal nerve. Branches supply the coccygeus muscle and the postanal skin near the tip of the coccyx.

SACRAL SYMPATHETIC TRUNKS

The trunks cross the pelvic brim behind the common iliac vessels and lie in the concavity of the sacrum *medial* to the anterior sacral foramina (Fig. 5.55). Each has

characteristically four ganglia. The trunks lie parallel with the lateral margin of the sacrum and converge at the front of the coccyx to unite at a small swelling, the *ganglion impar*.

Somatic branches are given off to all the sacral nerves (lower limb and perineum), and smaller vascular filaments to the lateral and median sacral vessels. Visceral branches leave the ganglia to mingle with the inferior hypogastric plexus (pelvic viscera).

INFERIOR HYPOGASTRIC PLEXUSES

There are two inferior hypogastric plexuses, right and left, collectively forming the **pelvic plexus**. They must not be confused with the single midline superior hypogastric plexus (p. 365).

The **inferior hypogastric plexus** is an autonomic plexus on the side wall of the pelvis, lateral to the rectum and within the parietal pelvic fascia. Its sympathetic components are derived from the superior hypogastric plexus (p. 365) by the hypogastric nerve and by branches from the sacral ganglia of the sympathetic trunk. Its parasympathetic components are carried by branches from S2, 3 and 4 nerves; these are the *pelvic splanchnic nerves*. The plan of its constituent parts is indicated in Figure 5.63.

The plexus is a coarse, flat meshwork, enlarged in places in ganglia; it measures nearly 5 cm (2 in) in anteroposterior and about 2 cm in vertical dimension. About half the fibres in the hypogastric nerves are

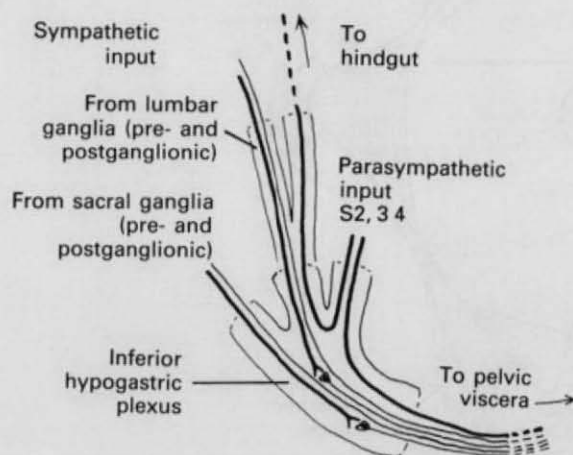


Fig. 5.63 Constituents of the inferior hypogastric plexus. Preganglionic (myelinated) sympathetic and parasympathetic fibres whose cell bodies are in the lateral horn of the spinal cord are shown in heavy line; postganglionic (unmyelinated) fibres with cell bodies in sympathetic trunk ganglia are in slender line.

myelinated (preganglionic) and they relay in the ganglia of the inferior hypogastric plexus (Fig. 5.63). The remaining sympathetic fibres and all the parasympathetic fibres pass through without relay. The parasympathetic motor and secretomotor fibres relay in the walls of the viscera.

The branches of the hypogastric plexuses are wholly visceral and run in leashes of nerves bound up in condensed bundles of fibrous tissue. In their passage through the fibrous tissue above the pelvic floor they are accompanied by visceral branches of the internal iliac artery and vein; these neurovascular bundles in their fibrous tissue condensations produce certain of the named 'ligaments' of the pelvic viscera (e.g. lateral ligaments of the bladder, of the cervix, of the rectum). While it is well established that sympathetic vasoconstrictor fibres accompany all arteries to the pelvic viscera, much ignorance still exists as to the exact course of certain of the motor and sensory fibres to these organs. In general it appears that the muscles of the bladder (detrusor muscle) and rectum are innervated by the pelvic splanchnics, the smooth muscle of the internal sphincter of the bladder through the superior hypogastric plexus and the smooth muscle of the internal sphincter of the anal canal by branches from the sacral ganglia which pass through the pelvic plexuses. The course of the afferent fibres is less well understood. Normal sensations of distension of bladder and rectum probably pass through the pelvic splanchnic nerves; pain fibres probably take the same course, though some pass in the hypogastric nerves as well. Pain fibres from the body of the uterus and the upper part of the cervix appear to run with the hypogastric nerves, the cell bodies being in the dorsal root ganglia of T10–L1 nerves, but pain fibres from the lower cervix travel with the parasympathetic nerves (p. 388).

As well as being motor to the smooth muscle of the pelvic viscera the pelvic splanchnic nerves supply the colon from the splenic flexure distally. Many of these branches run up from the inferior hypogastric plexus to the superior hypogastric plexus and leave it by a separate trunk which joins the inferior mesenteric artery, by which they are distributed to the descending and sigmoid colon; others make their own way up behind the peritoneum without becoming involved in the superior plexus.

Thus in the pelvis the two parts of the autonomic system conform to their *motor* functions higher up. The pelvic parasympathetics are motor to the emptying muscle of the bladder, and of the gut from splenic flexure to rectum. They are secretomotor to the gut. The sympathetics are motor to the visceral muscle sphincters of the bladder and anal canal; they are

motor, too, to the ductus deferens, seminal vesicles and prostatic muscle. The sympathetic probably also supplies motor fibres to the uterine muscle (p. 388).

The *sensory* supply to abdominal viscera and gonads is sympathetic, and this includes the descending colon. But there is a change of sensory supply to the derivatives of the cloaca. Bladder, rectal ampulla and anal canal receive sensory fibres from the pelvic parasympathetics. So, too, do the lower cervix and upper vagina, but the body of the uterus receives its sensory supply from the sympathetic. Thus pain from the prostate or rectum, mediated by the pelvic splanchnics to S2–4 segments, may be referred to these dermatomes (posterior femoral cutaneous nerve) and so be mistaken for 'sciatica'.

PART 17 PERINEUM

The **perineum** consists of that part of the trunk of the body caudal to the pelvic diaphragm (levator ani and coccygeus). A line joining the *anterior* parts of the ischial tuberosities divides this diamond-shaped area

into a larger posterior anal region and a smaller anterior urogenital region (Fig. 5.64). The anal region contains the anal canal and the ischioanal fossae with their contents. Its sides are formed by the sacrotuberous ligaments (covered by the lower border of gluteus maximus) and its base is formed by the line between the anterior parts of the ischial tuberosities. Its contents are the same in each sex. The urogenital region lies in front of the line joining the anterior parts of the ischial tuberosities, and is bounded laterally by the conjoined ischiopubic rami. In each sex it contains the external genitalia.

Cutaneous nerves

The skin of each side of the anal region is supplied by the inferior rectal nerve (S3, 4), the perineal branch of S4 and some twigs from the coccygeal plexus (S5).

In the urogenital region, the ilioinguinal nerve (L1) supplies the anterior third of the scrotum (labium majus) down to the anterior axial line. The skin of the penis (clitoris) is supplied by the dorsal nerve (S2). The posterior two-thirds of the scrotum (labium majus) is supplied laterally by the perineal branch of the posterior femoral cutaneous nerve and medially (labium minus) by scrotal (labial) branches of the perineal branch of the

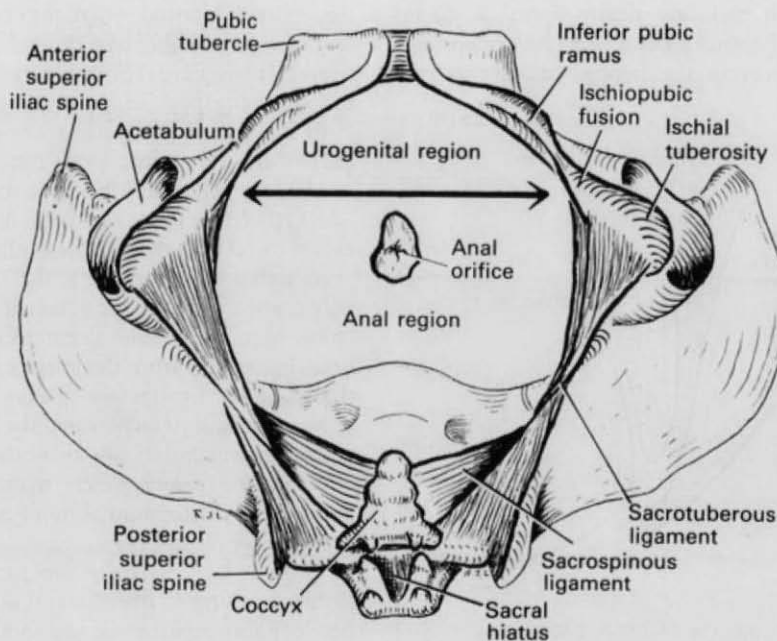


Fig. 5.64 Urogenital and anal regions of the pelvic outlet. The dividing line (arrowed) joins the ischiopubic fusions. The anterior urogenital region is triangular and contains the external genitalia. The anal region is a pentagon and contains the anal canal and ischioanal fossae.

pudendal nerve (S3). On the scrotum and labia note the *gap in the sequence* of dermatomes between L1 at the front and S3 farther back. For this reason a pudendal nerve block will not anaesthetize the whole vulva; the anterior part must be locally infiltrated to supplement the main nerve block.

ANAL REGION

Anal canal

The anal canal is the last 4 cm of the alimentary tract and is developed from the anorectal canal and proctodeum (p. 43 and 380). Like the rest of the gut it is a tube of muscle but the fibres are all circular, consisting of the internal and external anal sphincters, which are composed of visceral and skeletal muscle respectively. These sphincters, assisted by the configuration of the mucous membrane, hold it continually closed except for the temporary passage of flatus and faeces. The junction of rectum and anal canal is at the pelvic floor, i.e. at the level where the puborectalis part of levator ani clasps the gut and angles it forwards (Fig. 5.65). From this right-angled junction with the rectum the anal canal passes downwards and somewhat backwards to the skin of the perineum.

The muscles of the anal canal can be regarded as forming 'a tube within a funnel' (Parks) (Fig. 5.66). The sides of the upper part of the funnel are the levator ani muscles, and the stem of the funnel is the external sphincter which is continuous with levator ani. The

tube inside the stem of the funnel is the internal sphincter which is a thickened continuation of the inner circular layer of rectal muscle. Internally lies the submucosa and mucous membrane. To this simple model of the basic structure of the anal canal further details can be added.

External anal sphincter

The sphincter has been confusingly described as having deep, superficial and subcutaneous parts, based largely on the attachments of the middle (superficial) part, but the parts blend with one another to form a continuous tube and should not be regarded as separate entities.

The rectal end (deep part) of this sphincter of circular skeletal muscle fibres blends with the puborectalis part of levator ani (Fig. 5.66), except of course in the midline at the front where there are no levator ani fibres; here the sphincter fibres alone complete the ring. The region where puborectalis fuses with the external sphincter (which is also the level of the upper end of the internal sphincter) is called by clinicians the **anorectal ring**, and is palpable on rectal examination (p. 380). The middle (superficial) part is elliptical rather than round, being attached to the tip of the coccyx at the back (superficial to the anococcygeal ligament) and to the perineal body in front. It is the only part of the sphincter with a bony attachment. The subcutaneous part is a circular ring of fibres whose lower end curves inwards to lie below the lower end of the internal sphincter. This submucosal apposition of the two

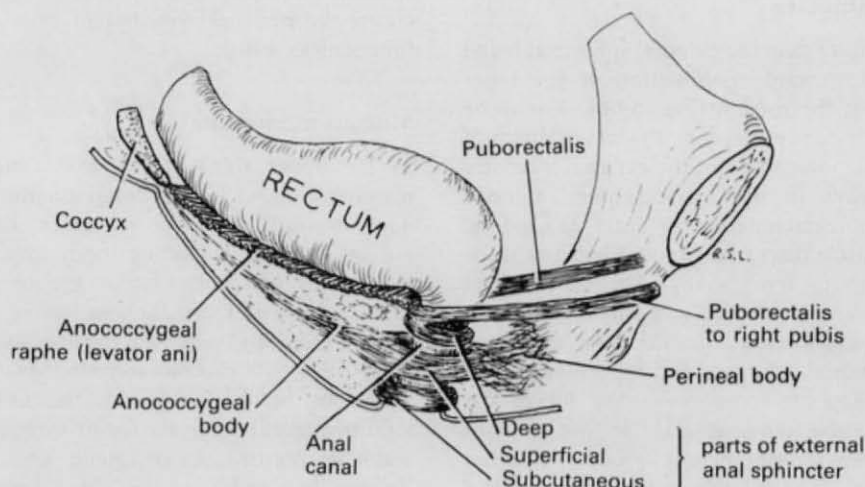


Fig. 5.65 Puborectalis and the external anal sphincter from the right. The three traditional parts of the sphincter are shown, but they merge with one another and the deep part is continuous with the puborectalis part of levator ani.

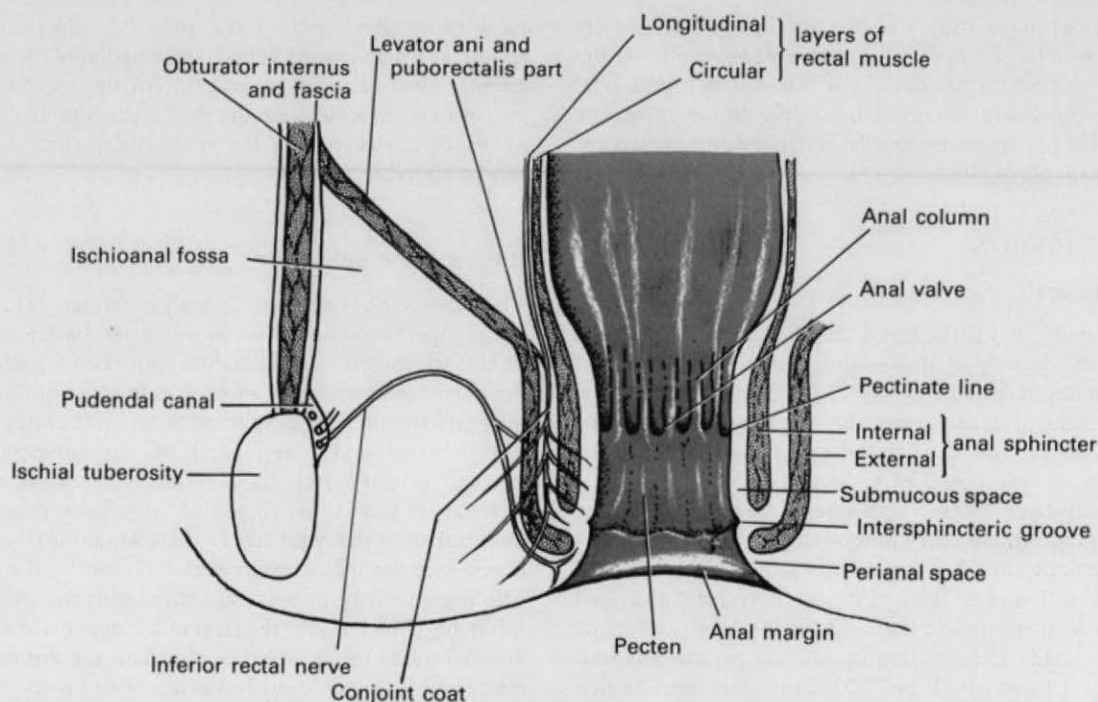


Fig. 5.66 Coronal section of the anal canal and the right ischioanal (ischioanal) fossa. For clarity only the inferior rectal nerve is shown leaving the pudendal nerve in the pudendal canal; the corresponding vessels pursue a similar course across the fossa.

sphincters in the lower part of the canal gives rise to the palpable *intersphincteric groove*.

Internal anal sphincter

This is much simpler than the external sphincter, being the thickened downward continuation of the inner circular muscle of the rectum (Fig. 5.66). It may be 5 mm thick, but it does not occupy the whole length of the canal since the lowest part of the external sphincter comes to lie below its well-marked rounded lower border. At the anorectal junction the outer longitudinal layer of rectal muscle fuses with fibrous elements of the puborectalis sling to form a thin fibroelastic sheet known as the *conjoint longitudinal coat* which runs down between the two sphincters. Strands from this sheet penetrate the internal sphincter and the lower part of the external sphincter; some reach the fat of the ischioanal fossa, the perianal skin or the mucous membrane of the intersphincteric groove. Whether some of them form distinct fascial septa is debated. It is possible that the puckering of perianal skin is due to some of these fibroelastic strands, but some investigators describe visceral muscle fibres in this region, the

lowest of which form the so-called *corrugator cutis ani* muscle which if present is considered part of the panniculus carnosus and quite separate from either sphincter. In many quadrupeds it crinkles and therefore cleans the perianal skin, but in man it is an almost functionless vestige.

Mucous membrane

In the upper third of the anal canal the mucous membrane shows up to a dozen longitudinal ridges, the *anal columns*. They are prominent in children but often not in adults or dissecting room specimens. At their lower ends adjacent columns are joined together by small horizontal folds, the *anal valves*; the pockets so formed above the valves are the *anal sinuses*, into which open up to 10 mucous-secreting *anal glands*. These must not be confused with the ordinary mucosal intestinal glands (crypts) found throughout the small and large intestine; the anal glands are submucosal (like Brunner's glands in the duodenum), and some penetrate into the internal sphincter. Infection in these glands results in anal abscesses and fistulae. The level of the anal valves is the *pectinate line* (sometimes called the

dentate line) below which is a smooth-surfaced area, the pecten, which extends down to the intersphincteric groove. Below the groove is a truly cutaneous area, continuous at the anus (anal margin) with the skin of the buttock. Histologically the lining below the groove is typical skin with stratified squamous keratinizing epithelium, hair follicles, sebaceous glands and sweat glands. The lining of the pecten is sometimes confusingly called anal skin; there is stratified squamous epithelium, but it is non-keratinizing and there are no hair follicles, sebaceous glands or sweat glands. In general the anal column area, being continuous with rectal mucosa, may be expected to have typical columnar intestinal cells and crypts, but immediately above the pectinate line there is a zone of variable epithelial structure, with columnar and stratified squamous epithelium often being mixed so that there is no abrupt line of change from the single-layered gut type to multilayered pecten type. (This contrasts with the gastro-oesophageal junction where there is an abrupt change from stratified squamous to columnar epithelium.) Anal fissures extend from the anal margin to the pectinate line.

The **intersphincteric groove** probably corresponds to 'Hilton's white line', beloved of older textbooks, but the line was never clearly defined. It has no place in the modern understanding of alimentary canal structure and the term must be abandoned, as it should have been years ago.

In the region of the intersphincteric groove the mucous membrane is particularly firmly attached to the lower part of the internal sphincter. The submucosa above this is lax and known clinically as the *submucous space*. The name *perianal space* is given to the area occupied by the fatty subcutaneous tissue adjacent to the anal margin. This tissue overlies the base of the ischioanal fossa which is occupied by more coarsely lobulated fat; whether these two spaces are separated by a septum that could be called the perianal fascia (possibly continuous with fibres from the conjoint coat that have penetrated the external sphincter) is debatable. Perianal abscess may spread between the internal and external sphincters.

The lining of the upper part of the anal canal is embryologically derived from the cloaca, i.e. it is endodermal, the lower part is from the proctodeum or anal pit and therefore ectodermal (p. 43). The dividing line between these territories is usually considered to be at the pectinate line. The fact that there are different origins for the upper and lower parts is highly relevant for blood and nerve supplies and lymph drainage.

Blood supply

Branches of the superior rectal artery supply the upper end of the canal, their terminations lying within the anal columns. A small part of the muscular wall is supplied by the middle rectal and median sacral arteries, while the lower end, including its mucous membrane, receives the ends of the inferior rectal vessels which have crossed the ischioanal fossae. Within the walls there is good anastomosis between the various vessels.

The veins correspond to the above arteries and are continuous with the *rectal venous plexuses* (p. 380). The upper part of the canal and plexus drains via the superior rectal and inferior mesenteric veins to the portal system, whereas the lower end drains to the internal iliac veins through the inferior and middle rectal veins. The anal canal is thus a site of portal-systemic anastomosis (p. 351), the union being in the region of the anal columns in the upper third. Note that although the vessels taking part in the anastomosis and plexus are called rectal, the site of anastomosis is in the anal canal, not the rectum.

It has been suggested that the internal rectal venous plexus helps the mucous membrane to form three cushion-like masses in the 3, 7 and 11 o'clock positions, corresponding to the common sites for haemorrhoids (piles) which are varicosities at these sites. These spongy mucosal cushions assist the sphincter in maintaining watertight closure of the canal. Straining at stool apparently increases the varicosities, but, contrary to what might be expected, the incidence of haemorrhoids in portal hypertension is no greater than in patients with normal portal pressure, and their precise cause remains obscure.

Lymph drainage

The lymph drainage shows a watershed corresponding to the vascular pattern. The upper canal drains to internal iliac nodes, whereas lymph from the lower end passes to the (palpable) superficial inguinal group.

Nerve supply

The (somatic) inferior rectal branches (S2) of the pudendal nerves supply the external sphincter and also provide the sensory supply for the lower end of the canal which like skin is highly sensitive. The external sphincter has a high proportion of slow twitch fibres and shows constant electromyographic activity even in sleep and under light anaesthesia. Autonomic nerves pass to the internal sphincter and the upper end.

Sympathetic fibres from the pelvic plexus, with preganglionic cell bodies in the first two lumbar segments of the cord, cause contraction of the internal sphincter, and pelvic splanchnic (parasympathetic) nerves relax it. Afferent fibres from the upper end of the canal run mainly with the pelvic splanchnics.

The *anal* and *bulbocavernosus reflexes* have been described on page 29.

Defaecation

Several factors contribute to normal anal continence: contraction of puborectalis and the external sphincter, maintenance of the angle between rectum and anal canal with abdominal pressure flattening the lower anterior rectal wall over the upper end of the canal, and the presence of mucosal cushions in the canal. The internal sphincter, although assisting closure, can only maintain continence if there is no distension (which causes relaxation of the sphincter). The rectum can accommodate itself to receive a certain amount of colonic content without any significant increase in pressure. There are no specialized receptors in the rectal wall, but they are present in the anal canal where gas, fluid and solid can be distinguished by the cerebral cortex, and there are also stretch receptors in levator ani and the perirectal tissues. When increasing rectal pressure causes faeces to enter the upper anal canal, the external sphincter contracts and forces the contents back into the rectum. If only gas enters, its presence can be tested by a slight conscious increase of abdominal pressure which will let it escape. The feeling of distension (like bladder distension) is conveyed within the spinal cord by the gracile tracts. Defaecation is allowed to occur by release of the cortical inhibition that developed during childhood training. The pathways in the spinal cord probably run with the lateral corticospinal fibres (like those for the control of micturition — p. 382). Abdominal pressure is increased, puborectalis relaxes and the anorectal angle straightens with relaxation of the external sphincter and contraction of the lower colon and rectum (via its parasympathetic supply).

Incontinence will follow damage to the external sphincter, e.g. in obstetrics and perineal operations, but often the cause is obscure; some cases may be due to pudendal nerve entrapment at the level of the sacrospinous ligament. In cerebral or spinal cord lesions there may be loss of cortical control.

Ischioanal (ischiorectal) fossa

The **ischioanal fossa** (formerly but illogically called

ischiorectal) is a wedge-shaped space filled with fat lateral to the anal canal (Figs 5.66 and 5.68A). The **base** of each fossa is above the skin over the anal region of the perineum. The anal canal and the sloping levator ani muscles form the **medial wall** of each fossa, while the **lateral wall** is formed by the ischial tuberosity below with obturator internus above. The sharp **apex** of the wedge is where the medial and lateral walls meet (where levator ani is attached to its tendinous origin over the obturator fascia). At the base the anterior boundary is the posterior border of the perineal body and urogenital diaphragm (p. 406), and the posterior boundary is the sacrotuberous ligament overlapped by the lower border of gluteus maximus.

Each fossa has an anterior and a posterior recess. The **anterior recess** passes forwards above the urogenital diaphragm as far as the posterior surface of the body of the pubis; the **posterior recess** is smaller and extends from the lower border of gluteus maximus to the underlying sacrotuberous ligament.

Although the anococcygeal body (deep to perineal skin, see below) separates the two fossae low down, they communicate with one another through loose tissue *behind the anal canal higher up*, providing a horse-shoe-shaped path for the spread of infection from one fossa to the other. The name ischiorectal was a misnomer, since the levator ani muscles keep the spaces separated from the rectum.

Each fossa contains the ischioanal fat pad, the pudendal canal, and a number of vessels and nerves. The **ischioanal fat pad** allows for dilatation of the anal canal during defaecation and of the vagina during parturition when the passage of the fetal head virtually obliterates the space.

The **pudendal canal** (of Alcock) is a connective tissue sheath in the lower lateral wall of the fossa, overlying obturator internus and the medial side of the ischial tuberosity. It contains the **pudendal nerve** and **internal pudendal vessels** (Fig. 5.67), which it conducts from the lesser sciatic notch to the deep perineal pouch (above the perineal membrane and containing the urogenital diaphragm — p. 406).

The canal is most simply considered as being formed by a splitting of the obturator fascia joining the falci-form process of the sacrotuberous ligament. An alternative theory suggests that another sheet of tissue, the lunate fascia (not recognized in official terminology), overlies the obturator fascia, remaining separate from the obturator fascia low down where it joins the falci-form process, and at the apex of the fossa turning medially to cover the under surface of levator ani.

Running transversely across the fossa from the proximal end of the pudendal canal towards the anus

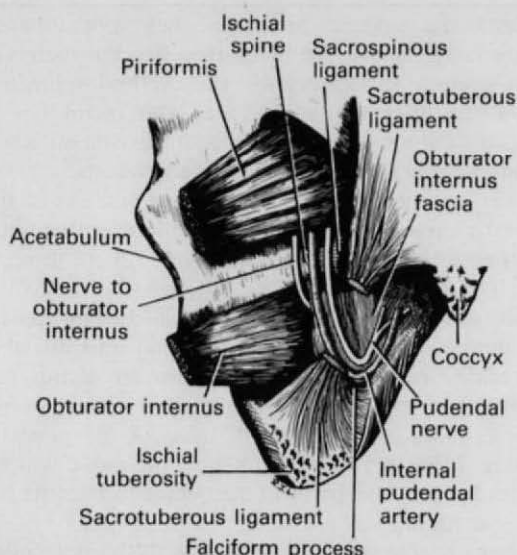


Fig. 5.67 Lateral wall of the left ischioanal fossa from behind, with the connective tissue of the pudendal canal removed to show the pudendal nerve and vessels running forwards on the medial side of the ischial tuberosity.

are the **inferior rectal branches** of the pudendal nerve and internal pudendal vessels. Their course is not straight across the base of the fossa, but arches convexly upwards through the fat towards the apex and then downwards to the anal canal. Incisions to drain ischioanal abscesses usually do not interfere with them. Accompanied by the vessels, the nerve breaks up into several branches which supply the external sphincter, mucous membrane of the lower anal canal and perianal skin. The important feature about the accompanying veins is that they link up in the upper part of the anal canal with superior rectal tributaries which belong to the portal system (p. 403).

At the *front* of the fossa the *posterior scrotal (labial) nerves and vessels* (from the pudendals) pursue a very short course in it before leaving to pass superficially into the urogenital region. At the *back* of the fossa the *perineal branch of S4 nerve* and the *perforating cutaneous nerve* are also in the fossa for a very short distance. The former runs into levator ani, and the latter pierces the sacrotuberous ligament to become cutaneous round the lower border of gluteus maximus.

Cutaneous nerves

The skin of the anal region is supplied by the inferior rectal nerve (S3, 4), the perineal branch of S4 and some twigs from the coccygeal plexus (S5).

Perineal body

The perineal body, now properly called the **central perineal tendon**, is an elongated midline fibromuscular mass to which a number of muscles gain attachment. It lies in front of the anal canal and behind the posterior border of the perineal membrane (p. 406) to which it is also attached, and therefore in the female it is between the anal canal and the pudendal cleft (Figs 5.65 and 5.68). The rectovesical (rectovaginal) septum blends into it above. The muscles running into it include parts of two sphincters — the external anal and external urethral — and four other pairs: levator prostatae (pubovaginalis) part of levator ani, bulbospongiosus, and the superficial and deep transverse perinei. Its position and connexions provide an important stabilizing influence for pelvic and perineal structures. Injury to it during childbirth may weaken the pelvic floor and lead to prolapse of the vagina and uterus. It should be noted that obstetricians use the term *perineum* to mean only the perineal body and not the whole perineal region below the pelvic floor.

Anococcygeal ligament

The fibres of the iliococcygeus and pubococcygeus parts of levator ani interdigitate in front of the coccyx as the *anococcygeal raphe* which extends from the tip of the coccyx to the anorectal junction. Raphe and skin diverge from each other as they pass forwards to the upper and lower ends of the anal canal. In the midline space between them is a fibromuscular mass of tissue, the **anococcygeal ligament**, which separates the two ischioanal fossae behind the lower part of the anal canal (Fig. 5.68A). Fibres of the intermediate (superficialis) part of the external sphincter pass superficial to the anococcygeal ligament to become attached to the tip of the coccyx. Lateral to this the sacrotuberous ligament limits the fossa.

The **pudendal nerve** and **internal pudendal vessels** leave the pelvis through the greater sciatic foramen, passing beneath the lower border of piriformis to reach the buttock (Fig. 5.67). Their course in the buttock is short. They turn and enter the lesser sciatic foramen, the vessels passing over the tip of the spine of the ischium, the nerve more medially over the sacrospinous ligament. They enter the pudendal canal, which is in continuity with the lesser sciatic foramen, and run forwards in it to supply the perineum.

Note that the nerve to obturator internus, which has crossed the base of the ischial spine, is now above this level and, moreover, is beneath the fascia over the muscle, and sinks into the fleshy fibres to innervate them (Fig. 5.67). The branches of the pudendal nerve

and internal pudendal artery are considered below (p. 410).

PART 18

MALE UROGENITAL REGION

Among the principal contents of this region are a small mass of muscle constituting the urogenital diaphragm, and three layers of fascia: the superior and inferior fasciae of the urogenital diaphragm (the inferior being commonly called the perineal membrane), and the superficial perineal fascia (of Colles) which is the continuation into the perineum of the membranous layer of superficial fascia of the anterior abdominal wall (Scarpa's fascia). The area between the two diaphragmatic layers of fascia is the deep perineal pouch, which contains the urogenital diaphragm with the membranous part of the urethra passing through it centrally, the internal pudendal vessels, dorsal nerve of penis and perineal nerve at the sides, and the paired bulbourethral glands (of Cowper) at the sides of the urethra. The superficial perineal fascia is attached to the back of the perineal membrane and forms a sheath for the penis and scrotum. The area between this fascia and the perineal membrane is the superficial perineal pouch which contains the root of the penis, the superficial perineal muscles and some branches of the pudendal nerve and vessels, together with the pendulous part of the penis, the testes and spermatic cords.

DEEP PERINEAL POUCH

The **perineal membrane** forms the lower boundary of the **deep perineal pouch** (Fig. 5.68B) and is an unyielding sheet of fibrous tissue which forms the basis upon which the penis and penile musculature are fixed (Fig. 5.68A). It is attached on either side to the ischiopubic rami from just behind the subpubic angle back to the level of the anterior part of the ischial tuberosities, along a ridge which lies on the inner part of the medial surface of each ramus. Its anterior border forms the *transverse perineal ligament*, and there is a small gap between this and the arcuate pubic ligament through which the deep dorsal vein of the penis passes to reach the vesicoprostatic plexus. Its anteroposterior extent is about 3.5 cm (1 $\frac{1}{2}$ in), and the *superficial perineal fascia* (of Colles) is attached along its posterior border, which fuses centrally with the perineal body. When standing

upright, the perineal membrane lies approximately horizontally. Above the membrane lies the membranous urethra surrounded by the urethral sphincter, below the apex of the prostate. The membrane is pierced by the urethra, the ducts of the bulbourethral glands, and by foramina for nerves and vessels.

After leaving the prostate just in front of the apex, the prostatic urethra (p. 385) becomes the **membranous urethra** which passes down for about 1.5 cm through the deep perineal pouch, i.e. through the urogenital diaphragm which is the muscle that fills the pouch. The membranous urethra is the shortest and least dilatable part of the urethra and does not contain any glands, but in the upper part of its wall there are some visceral muscle fibres continuous with those of the prostatic urethra. It lies 2.5 cm (1 in) behind the pubic symphysis and pierces the perineal membrane to become the penile urethra.

Above the perineal membrane is the muscle mass called the **urogenital diaphragm**. This consists of the (single) *sphincter urethrae*, often called clinically the external urethral sphincter, and the paired *deep transverse perineal muscles*. It is important to appreciate that this rather small mass of skeletal muscle does not form a flat sheet as illustrated in most anatomical texts. The deep transverse perineal muscles do run horizontally, from the ischiopubic rami to the perineal body, with some fibres merging with the sphincter muscle and a few crossing from one ramus to the other, but the urethral sphincter itself is roughly pear-shaped. The thinner upper end of the 'pear' extends upwards out of the deep perineal pouch to surround the lower part of the prostatic urethra; the lower more bulbous part is below the apex of the prostate and above the perineal membrane (within the deep perineal pouch). Some of its fibres arise from the pubic rami and pass as U-shaped loops in front of and behind the urethra, some run from the transverse perineal ligament to the perineal body, and some completely encircle the urethra. Although consisting of skeletal muscle, the sphincter fibres are of smaller diameter than usual and are of the slow twitch variety, clearly distinguishing them from the most medial fibres of levator ani (*levator prostatae*), which are immediately adjacent but not attached to the sphincter. A further distinguishing feature is that the sphincter does not possess muscle spindles. The muscles of the urogenital diaphragm are supplied by the perineal branch of the pudendal nerve.

The **bulbourethral glands** (of Cowper) lie one on each side of the membranous urethra in the deep perineal pouch, i.e. above or deep to the perineal membrane, on a level between the prostate and the

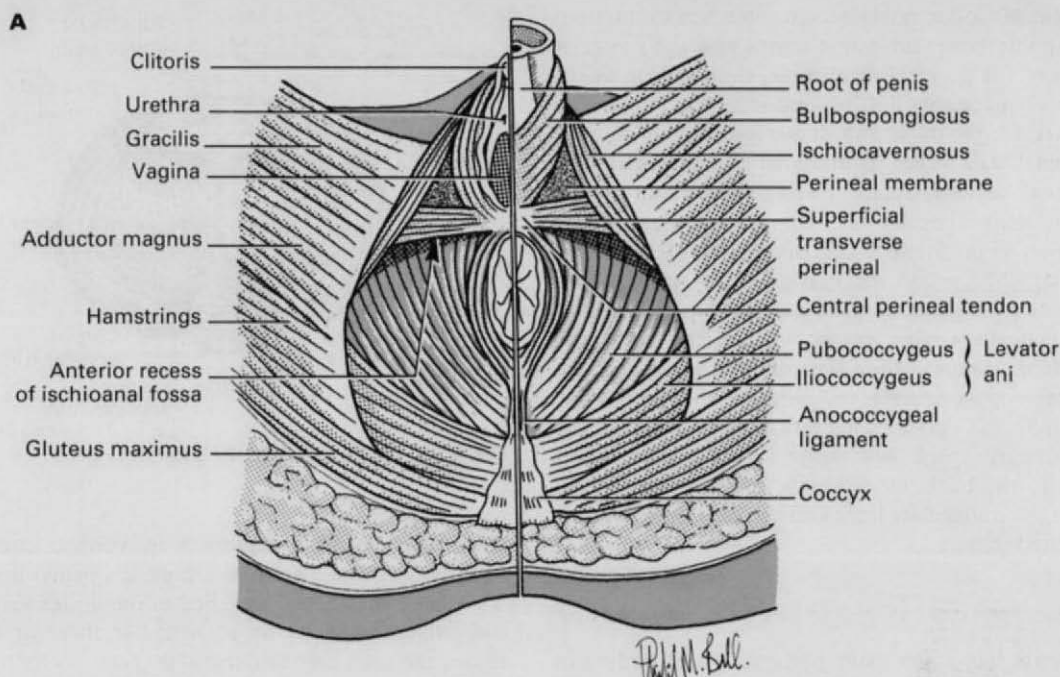
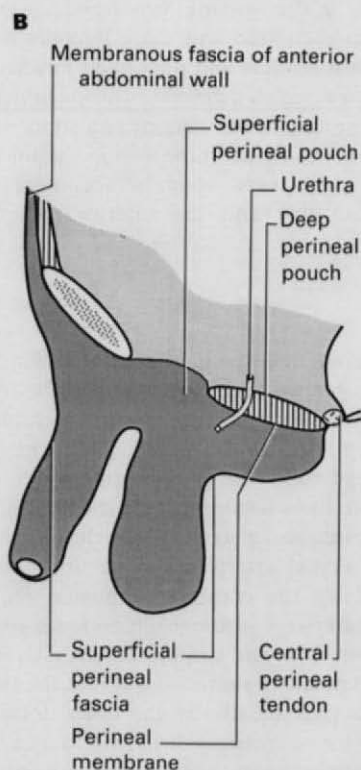


Fig. 5.68 Muscles of the perineal region and the perineal pouches. **A** Perineal muscles, female on the left and male on the right of the picture. **B** Diagrammatic representation of the perineal pouches in the male.



bulb of the penis and covered by the urethral sphincter. They are about 1 cm in diameter. The single duct from each, about 2.5 cm (1 in) long, runs parallel to the urethra and pierces the perineal membrane posterolateral to the urethra to open into the bulb of the penile urethra. They contribute a small amount to seminal fluid.

The upper boundary of the deep perineal pouch is ill-defined, being simply the part of the loose pelvic fascia that lies on top of the urogenital diaphragm and is therefore called its *superior fascia*. Note that it contrasts distinctly with the diaphragm's inferior fascia, which is the tough fibrous sheet rightly deserving its common name of perineal membrane.

SUPERFICIAL PERINEAL POUCH

This area (p. 406) contains the structures that lie below (superficial to) the perineal membrane and within the region bounded by the **superficial perineal fascia** (of Colles): the root of the penis, superficial perineal muscles and their associated vessels and nerves. Continuing into the perineum from the membranous fascia (of Scarpa) of the anterior abdominal wall (p. 241),

the edges of Colles' fascia become attached to the front of the pubic bone, the pubic ramus and the posterior margin of the perineal membrane, thus closing in the subfascial space that lies beneath it in continuity with the space deep to the membranous fascia of the anterior abdominal wall. From its marginal attachments in the urogenital region, Colles' fascia is projected into a bulbous scrotal expansion and a cylindrical penile expansion (Fig. 5.68B), the distal end of the latter being attached round the corona of the glans penis. Rupture of the penile urethra permits extravasation of urine beneath Colles' fascia whence the collection distends the tissues of the scrotum and penis and can then pass upwards over the anterior abdominal wall beneath Scarpa's fascia. Theoretically it could reach the submammary space and axilla, but it could never extend to the back, for Scarpa's fascia does not exist beyond the midaxillary lines and the subfascial space is obliterated there.

PENIS

The **penis** has as its main parts the root, body and glans. The **root** of the penis is attached to the inferior surface of the perineal membrane and consists of the (central) *bulb* of the penis with a *crus* on each side. Each crus is attached to the angle between the perineal membrane and the everted margin of the pubic ramus, receives the *deep artery* of the penis near its anterior end, and continues forwards to become the **corpus cavernosum**. The bulb is the posterior end of the **corpus spongiosum**. At the front of the root area, below the subpubic angle, the two corpora cavernosa are bound together side by side with the corpus spongiosum behind them (when the penis is dependent, but ventral to them when erect) to form the **body** of the penis. The penile urethra runs through the whole length of the corpus spongiosum from the bulb at the back to its expanded opposite end which is the **glans penis**. The urethra enters near the front of the bulb so that most of the bulge of the bulb is behind and below the urethra. The bulb has a slight (palpable) midline notch on its under surface and extends back towards the perineal body. The *arteries of the bulb* enter it near the urethra, which in this region receives the ducts of the bulbourethral glands (see above).

The corpus spongiosum and the two corpora cavernosa (Fig. 5.69) are each surrounded by a tough fibrous membrane, the **tunica albuginea** of the corpus (not to be confused with the tunica albuginea of the testis); that of the corpus spongiosum enlarges distally to enclose the glans. The fibrous sheaths of the corpora are fused together; between the corpora cavernosa this connec-

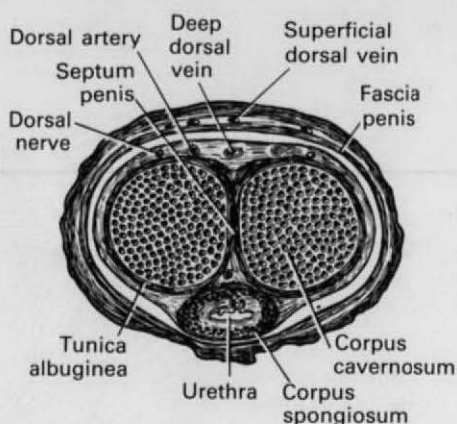


Fig. 5.69 Cross-section of the body of the penis.

tive tissue forms a *septum* with vertical comb-like strands. In some mammals a bone (*os penis*) lies here. The fused sheaths are attached to the under surface of the pubic symphysis by a triangular sheet of fibrous tissue, the *suspensory ligament of the penis*.

The three corpora thus fused together are loosely surrounded by the **fascia of the penis** (Buck's fascia), a cylindrical prolongation of Colles' fascia (p. 407) beneath which lie the midline *deep dorsal vein* with a *dorsal artery* on each side and more laterally a *dorsal nerve*. The skin is hairless and prolonged forwards in a fold, the **prepuce**, which invests the corona of the glans (its slightly projecting lower margin) and some or all of the rest of the glans. Beneath the skin in the midline is the *superficial dorsal vein* which is accompanied by lymphatics from skin and the anterior part of the urethra.

Blood supply

The penis receives three pairs of arteries which are all branches of the internal pudendals (p. 410). The artery to the bulb supplies the corpus spongiosum, including the glans. The deep artery of the penis supplies the corpus cavernosum, and the dorsal artery supplies skin, fascia and glans. Note the anastomosis, via the continuity of corpus spongiosum and glans, between the artery of the bulb and the dorsal artery; the deep artery *remains separate*, supplying the corpus cavernosum only and forming a closed system whose sole function is erection.

Venous return from the corpora is partly by way of veins that accompany the arteries and join the internal pudendal veins, but mostly by the deep dorsal vein which pierces the suspensory ligament, passes above the perineal membrane and enters the vesicoprostatic

venous plexus. The superficial dorsal vein drains the dorsal skin of the penis and divides to join the superficial external pudendal and great saphenous veins.

Lymph drainage

Lymphatics from the penile skin pass to superficial inguinal nodes, but the glans and the corpora drain to deep inguinal nodes. In cancerous spread the internal iliac nodes are rarely involved unless the inguinal nodes are first affected.

Nerve supply

The skin of the penis is supplied by the pudendal nerves (p. 411) via the posterior scrotal and dorsal nerves; the latter supply the glans. The dermatome mainly involved is S2. The bulbocavernosus and ischiocavernosus muscles which contract spasmodically during ejaculation are supplied by the perineal nerve (from the pudendal, S2, 3). The sympathetic nerves necessary for the initial stages of ejaculation (p. 411) are derived from L1 segment of the spinal cord via the superior and inferior hypogastric plexuses. The pelvic splanchnic nerves (S2, 3) provide the parasympathetic supply to the cavernous tissue of all three corpora and allow increased blood flow for erection (p. 411).

Circumcision

Ritual circumcision for religious or racial reasons is probably the oldest operation in the world. In children or adults circumcision may be required for a tightly constricting prepuce (*phimosis*). The prepuce is incised on the dorsum from the tip towards the base of the glans, dissecting away any adhesions, and then the incision is carried circumferentially, followed by suture of the skin edges.

SUPERFICIAL PERINEAL MUSCLES

The bulb and each crus of the penis are provided with overlying muscles — bulbospongiosus and ischiocavernosus respectively (Fig. 5.68A). In addition there is a transverse pair (superficial transverse perineal) along the posterior border of the perineal membrane. The three superficial perineal muscles of each side thus form a triangular pattern when viewed in the lithotomy position.

Bulbospongiosus is the current name for what was appropriately called compressor urethrae or accelerator urinae in former days. It arises from the perineal body

and in front of that from a median raphe that joins the pair together. Its posterior fibres are directed forwards and laterally over the bulb to be inserted into the perineal membrane. The fibres arising from the raphe are inserted into a dorsal fibrous expansion on the penis; the more posterior of these fibres clasp the corpus spongiosum, while the more anterior extend on to the corpus cavernosum. The older names indicate the action of the muscles; they empty the urethra (urine or semen).

Ischiocavernosus arises from the posterior part of the perineal membrane and from the ramus of the ischium. The fibres spiral forwards over the crus and are inserted into the upper surface of the commencement of the corpus cavernosum. Their function is to assist in the support of, and move slightly, the erect penis. The **superficial transverse perineal muscle** arises from the ischial ramus just behind the attachment of the perineal membrane and is inserted into the perineal body. It helps to stabilize the perineal body.

Nerve supply. All three muscles are supplied by the perineal branch of the pudendal nerve (S2, 3).

MALE URETHRA

The urethra consists of prostatic, membranous and spongy parts, with a total length of about 20 cm (8 in.). The prostatic and membranous parts have already been described (p. 385 and 406); clinically they are collectively called the posterior urethra.

The spongy or **penile urethra** (called by clinicians the anterior urethra), about 15 cm long (6 in.), is within the corpus spongiosum of the penis and can be divided into bulbous and pendulous parts. The posterior part of the corpus, attached to the under surface of the perineal membrane, is enlarged as the *bulb*. After piercing the perineal membrane the urethra enters the bulb and at once takes a right-angled curve forwards within the bulb. Beyond the root of the penis, with the organ in the flaccid state, the urethra continues as the *pendulous part*. Just proximal to the **external urethral meatus** at the tip of the glans there is a short dilated region, the *navicular fossa*. The lining here is stratified squamous epithelium, in contrast to the whole of the rest of the urethra which possesses the transitional epithelium typical of the urinary tract. The urethral mucosa displays some very small blind-ending pockets (lacunae) in the fossa and elsewhere in the pendulous part, and there are groups of *urethral glands* (of Littre) whose ducts open on the anterior and lateral surfaces of the urethra in a proximal direction (against the stream of urine). The empty urethra is horizontal in cross-section but the meatus is a vertical slit—hence the spiral

stream of urine, which delays separation of the stream into discrete droplets.

The urethra is *narrowest* at the bladder neck, in the membranous part, at the proximal end of the navicular fossa and at the external meatus, and shows *dilatations* in the prostatic part, bulb and navicular fossa. When passing a catheter it is vital to remember the 90° change of direction in the bulbar part before the membranous urethra is entered. Because of small mucosal folds at the glandular openings in the navicular fossa, any instruments being passed through the external meatus should initially be pointed downwards (towards the feet) when the penis is held up over the anterior abdominal wall, which is the position for inserting catheters and other instruments.

Blood supply

As with many tubular structures, there is no single 'artery to the urethra'; the blood supply is from any adjacent vessels as it passes through the prostate, urogenital diaphragm and corpus spongiosum.

Nerve supply

The mucous membrane of the penile part receives a branch from the perineal nerve, with filaments from the inferior hypogastric plexuses reaching more proximal parts. The urethral sphincters and the control of micturition have been described on page 382.

Development

The part of the urethra proximal to the openings of the ejaculatory ducts and prostatic utricle is formed, like the trigone of the bladder, from the lower ends of the mesonephric ducts and ureters that are absorbed into the bladder wall (p. 43). The rest is from the pelvic and phallic parts of the urogenital sinus and the genital tubercle, supplemented ventrally in the penile part by the fusion of the urogenital folds (p. 44). The epithelium of the navicular fossa (ectoderm from the genital tubercle) is a solid column that becomes canalized; if it fails to do so, and there is accompanying failure of complete fusion of the genital folds, the result is hypospadias — a midline opening on the ventral surface.

SCROTUM

The **scrotum** is a pouch of skin containing the testes and spermatic cords. The subcutaneous tissue has no fat, but contains a part of the panniculus carnosus, the

dartos muscle which sends a sheet into the midline fibrous *septum* of the scrotum. The rugosity of the skin is due to contraction of the dartos. The dartos is smooth muscle, and is supplied by sympathetic fibres probably carried by the genital branch of the genito-femoral nerve. Deep to dartos is the layer of the superficial fascia (Colles' fascia) attached behind to the posterior edge of the perineal membrane, at the sides to the ischiopubic rami and bodies of the pubic bones, and in front continuous with Scarpa's fascia.

Blood supply

The blood supply of the skin is from superficial and deep external pudendal arteries (from the femoral). Posteriorly there are some branches from the internal pudendal artery. Venous drainage is by external pudendal veins, superficial and deep, to the great saphenous vein (Fig. 3.3, p. 148).

Lymph drainage

Lymph drainage is to the medial group of superficial inguinal nodes.

Nerve supply

The anterior axial line (p. 24) crosses the scrotum. The anterior one-third of the scrotal skin is supplied by the ilioinguinal nerve (L1). The posterior two-thirds is supplied by scrotal branches of the perineal nerve (S3), reinforced laterally by the perineal branch of the posterior femoral cutaneous nerve (S2).

Development

The scrotum develops from the labioscrotal swellings that lie lateral to the urogenital folds on either side of the urogenital membrane (p. 44). (The same folds in the female form the labia majora.)

PERINEAL VESSELS AND NERVES

The **internal pudendal artery** (p. 396) enters the deep perineal pouch from the anterior end of the pudendal canal (from the posterior end of which it gives off its *inferior rectal branch*), and passes forwards along the ischiopubic ramus above the perineal membrane, with the dorsal nerve of penis above it and the perineal nerve below it. The posterior angle of the membrane is probably pierced by the *perineal branch* of the artery (if it has not arisen more proximally), which gives origin to *posterior scrotal* and *transverse perineal* branches. Further

forward it gives off the *artery to the bulb*, which pierces the membrane alongside the urethra and behind the bulbourethral duct to enter the corpus spongiosum. It gives branches to the cavernous tissue of this corpus and passes forwards to supply the glans penis. It has no anastomosis with the arteries of the corpora cavernosa, but through the glans it does anastomose with the dorsal arteries (see below).

Near the anterior margin of the perineal membrane the internal pudendal artery divides into its terminal branches, the deep and dorsal arteries of the penis. The *deep artery* pierces the membrane to enter the crus of the penis and supplies, by its *helicine branches*, the erectile cavernous tissue of the corpus cavernosum. The *dorsal artery* pierces the membrane and passes along the medial surface of the crus against the membrane to reach the dorsum of the penis. The dorsal arteries of each side pierce the suspensory ligament and run forward, alongside the median deep dorsal vein and with the dorsal nerves laterally, between the fascia of the penis and the fibrous sheaths of the corpora cavernosa. The arteries pass to the glans where they anastomose with the terminal branches of the arteries to the bulb.

The **deep dorsal vein** of the penis drains most of the blood from the corpora. It runs proximally in the midline and pierces the suspensory ligament to pass upwards in the gap between the pubic symphysis (arcuate pubic ligament) and the perineal membrane. Continuing backwards in the midline it enters the pelvis by passing between the two puboprostatic ligaments and joins the vesicoprostatic plexus.

The **pudendal nerve** (p. 398), after giving off its *inferior rectal branch* at the posterior end of the pudendal canal, divides within the canal into its terminal branches, the dorsal nerve of the penis and the perineal nerve. Both enter the deep perineal pouch, running forwards respectively above and below the internal pudendal artery. The *dorsal nerve of the penis* appears to be the direct continuation of the pudendal nerve. It pierces the anterior angle of the perineal membrane between the deep and dorsal arteries and then accompanies the dorsal artery on its lateral side. It supplies the skin of the penis and glans and gives branches to the corpus cavernosum. It has no branches in the deep perineal pouch.

The *perineal nerve*, which is the larger terminal branch of the pudendal, gives muscular branches to the superficial and deep perineal muscles and to the external urethral sphincter. The branch to bulbospongiosus supplies sensory fibres to the mucous membrane of the urethra. Either before or just after entering the deep perineal pouch the perineal nerve gives off the

posterior scrotal branches which run forwards superficial to the perineal membrane to supply scrotal skin.

Erection and ejaculation

The neural controls of erection and ejaculation are different; **erection** is *parasympathetic* and **ejaculation** is *sympathetic* and *somatic*. Impulses in the genital branches of the pelvic splanchnic nerves (parasympathetic) lead to vasodilatation of the arteries of the erectile tissue of the corpora (hence the old name, *nervi erigentes*). As the spongy tissue becomes engorged there may be some compression of the draining veins, but erection (whether reflex from physical stimulation or psychogenic) occurs mainly by increased arterial flow rather than by venous obstruction, although the mechanism for controlling venous outflow is not known.

The sympathetic outflow from segments T11 to L2 to the epididymis, ductus deferens, seminal vesicle, ejaculatory duct and prostate, and to the superficial trigonal muscle of the bladder, causes contraction of the smooth muscle of those structures, so causing the flow of seminal fluid into the prostatic urethra (*emission*). The internal urethral opening of the bladder neck becomes constricted so that there is no retrograde flow into the bladder. Rhythmic contraction of bulbospongiosus (supplied by the perineal nerve) compresses the penile urethra and expels the fluid. Orgasmic sensations run in the spinothalamic tract and are abolished by cord transection, but in transections above the lower thoracic segments (leaving the *more caudal sympathetic components* intact) ejaculation can still occur.

PART 19 FEMALE UROGENITAL REGION

The female external genitalia include the mons pubis, labia majora, labia minora, clitoris, vestibule of the vagina, bulb of the vestibule and the greater vestibular glands. Collectively they form the **vulva**. All the formations and structures seen in the male are present in the female, but greatly modified for functional reasons. The essential difference is the failure in the female of the midline fusion of the genital folds. The scrotum is represented by the labia majora and the corpus spongiosum by the labia minora and the bulb of the vestibule, with corresponding vessels and nerves.

The **mons pubis** is the mound of hairy skin and

subcutaneous fat in front of the pubic symphysis and pubic bones. It extends backwards on either side as the **labia majora** which are fatty cutaneous folds forming the boundary of the pudendal cleft. The round ligaments of the uterus end in the front of each labium. The labia are joined in front as the *anterior commissure*; at the back they fade away approaching the anus behind the vagina, and this area forms the *posterior commissure*.

The **labia minora** are cutaneous folds without fat lying internal to the labia majora and forming the boundaries of the vestibule of the vagina. Their front ends split to form the (dorsal) *prepuce* and (ventral) *frenulum* of the clitoris, while at the back they unite by a small skin fold, the *frenulum of the labia*.

The **clitoris** lies at the front ends of the labia minora. Although homologous with the penis, it is not associated with the urethra, so it is formed by two miniature *corpora cavernosa* without any corpus spongiosum. Its free extremity, the *glans*, is highly sensitive to sexual stimulation and is usually overlapped by the prepuce.

The **vestibule of the vagina**, bounded by the labia minora, contains the external urethral meatus and the vaginal orifice (p. 392) and the ducts of the greater vestibular glands.

The **female perineal membrane** is wider but weaker than in the male, being pierced transversely by the vagina (although the opening of the vagina in the vulva is longitudinal). It gives attachment to the *crura of the clitoris*, each of which is covered by an *ischiocavernosus* muscle. Medial to each crus, attached to the perineal membrane at the side of the vagina, is a mass of erectile tissue, the *bulb of the vestibule*, one on each side of the orifices of the vagina and urethra. They join in front of the urethral orifice and pass forwards to the glans of the clitoris. Each bulb is covered by a *bulbospongiosus* muscle, whose fibres extend from the perineal body round the vagina and urethra to the clitoris. They form a perineal sphincter for the vagina in addition to its pelvic sphincter (the pubovaginalis parts of levator ani).

The **greater vestibular glands** (of Bartholin) form pea-shaped masses less than 1 cm in diameter lying at the side of the vaginal opening, one behind the posterior end of each bulb and deep to bulbospongiosus (at 4 and 8 o'clock viewed from the lithotomy position). Each opens by a single duct 2 cm long into the posterolateral part of the vaginal orifice, in the groove between the labium minus and the hymen or its remains. The duct is subject to cyst formation, and the gland to ascending infection (*bartholinitis*). The glands may play a minor role in lubricating the lower vagina and are homologous with the bulbourethral (Cowper's) glands

of the male, but note that the glands in the male are deep to the perineal membrane, i.e. within the deep perineal pouch; in the female they are superficial to the membrane, so their ducts do not have to pierce it as they do in the male.

The **lesser vestibular glands** are very small mucous glands with minute openings between the urethral and vaginal openings.

The **hymen** is a mucosal fold of variable extent and thickness at the margins of the vaginal opening. It may be absent or may even completely close the opening, in which case it must be incised at the age when menstruation begins. Its remains after rupture by the first sexual intercourse may form small tags (*hymenal carunculae*).

The **female deep perineal pouch** is traversed by both the urethra and vagina, but as in the male (p. 406) contains the sphincter urethrae and the deep transverse perineal muscles, and comparable nerves and vessels. There is a similar but less well-defined superficial perineal fascia forming the boundary of the superficial perineal pouch, but instead of forming a sheath for the penis and scrotum (p. 407) it is centrally deficient because of the vulval slit. It is the fat of this superficial fascia that forms the labia majora.

The **perineal body** has been described on page 405). Lacking the rigid support of the more complete perineal membrane in the male, the perineal body is more mobile in the female. It helps to support the levator ani muscles above it, and its integrity is indispensable to the stability of the pelvic organs. It is liable to laceration during childbirth, and its obstetrical importance is indicated by its obstetrical name — simply, 'the perineum' (p. 405). A *midline episiotomy* involves incision through the posterior vaginal wall, perineal skin, perineal body and some fibres of the external anal sphincter, whereas the more common *posterolateral episiotomy* involves the vaginal wall, bulbospongiosus and the superficial transverse perineal muscle, skin over the ischioanal fossa and anterior (pubococcygeal) fibres of levator ani.

Female orgasm

Sexual excitement induces vascular dilatation and engorgement in the vulva, especially the labia minora and glans clitoris, and is due, as in the male, to parasympathetic activity. The vagina itself has no glands but becomes moistened by a transudation of fluid through the mucous membrane. The vestibular glands probably make a negligible contribution. At the climax there is some perineal skeletal muscle contraction.

PART 20

PELVIC JOINTS AND LIGAMENTS

The joints of the pelvis are the sacroiliac and sacrococcygeal joints and the pubic symphysis, while the ligaments of the pelvis (vertebropelvic ligaments) are the sacrotuberous, sacrospinous and iliolumbar.

Sacroiliac joint

The **sacroiliac joint** is a synovial joint between the auricular surfaces of the ilium (Fig. 3.55, p. 218) and sacrum (Fig. 6.82, p. 553). But for a synovial joint it is atypical on three counts: the cartilage on the sacrum is fibrocartilage, not hyaline; the surfaces are jagged (although smooth in the newborn); and there is very little movement.

The hip bone is strongly buttressed for weight-bearing between the auricular surface and the acetabulum (bears weight in standing) and between the auricular surface and ischial tuberosity (bears weight in sitting). The articular margins give attachment to the **capsule** and its lining of synovial membrane. In the adult, especially the male, the joint cavity is obliterated in places by fibrous bands which pass from one articular surface to the other.

Ligamentous bands, very strong posteriorly and weak anteriorly, surround the capsule. The **ventral sacroiliac ligament** is a flat band which joins the bones above and below the pelvic brim; stronger in the female, it indents a preauricular groove on the female ilium just below the pelvic brim.

On the dorsal surface a mass of ligaments attaches the sacrum to the ilium behind the joint. Most of them constitute the very strong **interosseous sacroiliac ligament**, whose fibres are attached to deep pits on the posterior surface of the lateral mass of the sacrum. The most superficial fibres form the **dorsal sacroiliac ligaments**. The posterior rami of the spinal nerves and vessels pass between the interosseous and dorsal ligaments.

Stability. The sacroiliac articulation depends entirely upon ligaments. The two joint surfaces lie in diverging planes; the weight of L5 vertebra tends to push the sacrum down towards the symphysis. There is no bony factor in stability; true the sacrum is wedge shaped, but in the reverse direction of a keystone. Opposing any simple gliding movement of the joint surfaces are the dorsal interosseous sacroiliac ligaments, and the iliolumbar ligament acting through

L5 vertebra, while opposing forward rotation of the sacral promontory around the joint are the sacrotuberous and sacrospinous ligaments (see below). While the ligaments are intact the bony surfaces so held in apposition are irregular enough to discourage gliding and rotation, but this bony factor is entirely dependent upon the integrity of the ligaments.

Note that the bony surfaces are not weight bearing. The body weight is suspended by the sacroiliac ligaments, which sling the sacrum below the iliac bones. Body weight tends to separate, not compress, the cartilage-covered articular surfaces.

The sacroiliac ligaments soften towards the later months of pregnancy and permit some slight rotation of the sacrum during parturition.

Accessory ligaments give added stability to the joint. The L5 vertebra is attached to the sacrum by the intervertebral disc and other ligaments (p. 537). Hence the *iliolumbar ligaments*, acting through this vertebra, assist in strengthening the bond between ilium and sacrum.

The *sacrotuberous* and *sacrospinous ligaments* (Fig. 5.51) are joined strongly to the sacrum (and coccyx) and to the ischium and help to stabilize the sacrum on the hip bone—in particular they oppose forward tilting of the sacral promontory.

Sacrotuberous ligament

The **sacrotuberous ligament** is a flat band of great strength. It is attached to the posterior border of the ilium between the posterior superior and posterior inferior iliac spines, to the transverse tubercles of the sacrum below the auricular surface, and to the upper part of the coccyx. From this wide area the ligament slopes down to the medial surface of the ischial tuberosity. The upper edge of the ischial attachment is prolonged forwards and attached to a curved ridge of bone. This prolongation is the *falciform process*; it lies just below the pudendal canal. The sacrotuberous ligament is narrower in the middle than at either end. Its gluteal surface gives origin to gluteus maximus. The ligament is said to be the phylogenetically degenerated tendon of origin of the long head of biceps femoris, into which a downward expansion of the ligament is attached. It is pierced by the perforating cutaneous nerve and branches of the inferior gluteal vessels and coccygeal nerves.

Sacrospinous ligament

The **sacrospinous ligament** lies on the pelvic aspect of the sacrotuberous ligament. It has a broad base which is attached to the side of the lower part of the

sacrum and the upper part of the coccyx. It narrows as it passes laterally, where its apex is attached to the spine of the ischium. The coccygeus muscle lies on the pelvic surface of the ligament. The ligament is the phylogenetically degenerated posterior surface of the coccygeus muscle.

The sacrotuberous and sacrospinous ligaments enclose the lesser sciatic foramen, whose lateral part is occupied by the emerging obturator internus muscle and whose medial part leads forwards into the pudendal canal above the falciform process of the sacrotuberous ligament (Fig. 5.67).

Iliolumbar ligament

The **iliolumbar ligament** is shaped like a V lying sideways, the apex of the V being attached to the transverse process of L5 vertebra, from which upper and lower bands fan outwards. The upper band passes to the iliac crest, giving partial origin to quadratus lumborum and becoming continuous with the lumbar fascia. The lower band, sometimes called the lumbosacral ligament, runs laterally and downwards to blend with the front of the ventral sacroiliac ligament.

Sacrococcygeal joint

The **sacrococcygeal joint** is a symphysis between the apex of the sacrum and the base of the coccyx, with an intervening disc of fibrocartilage. A short **ventral sacrococcygeal ligament** unites the bones at the front. Behind, there are two **dorsal sacrococcygeal ligaments** — a short *deep* one uniting the adjacent bones, and a *superficial* which closes over the sacral hiatus at the lower end of the sacral canal. At each side there is a **lateral sacrococcygeal ligament** running from the transverse process of the coccyx to the inferolateral angle of the sacrum, completing a foramen for the anterior ramus of the fifth sacral nerve. This ligament may become ossified — beware of a sacrum with five foramina on one or both sides! An extra one at the lower end is due to this ossified ligament (at the upper end, sacralization of L5 vertebra is responsible). A good deal of movement is possible in this articulation, but only flexion-extension. There is no side to side movement.

Pubic symphysis

The **pubic symphysis** as its name implies, is a secondary cartilaginous joint. The body surfaces of the pubes are each covered with a thin plate of hyaline

cartilage and the two sides are joined by a broad mass of transversely running fibres. Centrally a tissue-fluid space may develop, but it is never lined with synovial membrane. Ligamentous fibres forming the **superior pubic ligament** reinforce the symphysis above, and below it is strengthened by the **arcuate pubic ligament**.

PART 20

SUMMARY OF LUMBAR AND SACRAL PLEXUSES

The two plexuses have already been described, and the situations of their branches may be found in the descriptions of the appropriate regions. Their branches are summarized below, as was done for the brachial plexus (p. 122). The effects of injuries to lower limb nerves are described on page 214.

LUMBAR PLEXUS

After the anterior rami of the upper four lumbar nerves have supplied psoas and quadratus lumborum segmentally, they form the plexus (p. 362) in the substance of psoas major. The plexus (Fig. 5.70) innervates part of the lower abdominal wall, but is chiefly concerned in supplying skin and muscle 'borrowed from the trunk' by the lower limb. In this way it reinforces the sacral plexus, which is the true plexus of the lower limb (p. 24).

Branches of the lumbar plexus

- L1 — Iliohypogastric and ilioinguinal
- L1, 2 — Genitofemoral
- L2, 3 (posterior divisions) — Lateral femoral cutaneous
- L2, 3, 4 (posterior divisions) — Femoral
- L2, 3, 4 (anterior divisions) — Obturator

Iliohypogastric and ilioinguinal nerves (L1, p. 362)

These are only by convention included in the lumbar plexus. They are really just the first lumbar segmental body-wall nerve and its collateral branch, in series with the thoracic nerves (p. 20). Apart from supplying skin over the inguinal region and the front of the scrotum, they provide the important motor supply for the fibres of internal oblique and transversus that form the roof of the inguinal canal and reach the conjoint tendon (p. 304).

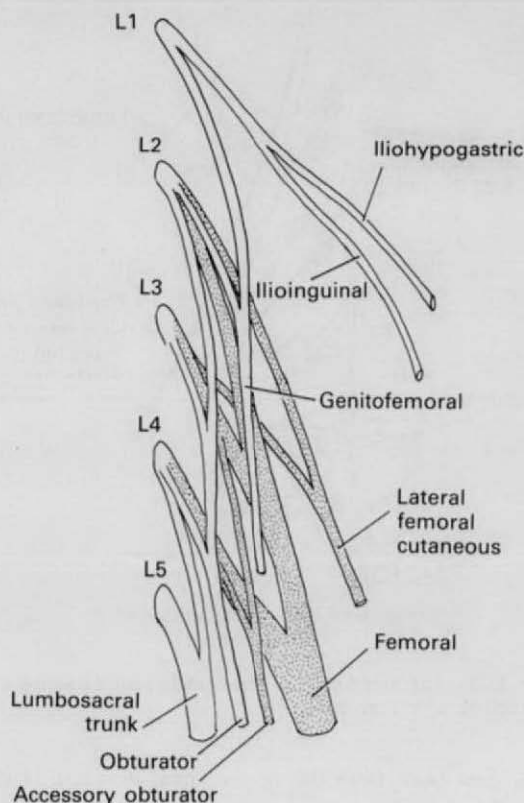


Fig. 5.70 Left lumbar plexus.

Genitofemoral nerve (L1, 2—best remembered segmentally as the ‘femorogenital’ nerve, pp. 146 and 363)

L1 is the *femoral* part, and supplies an area of skin below the middle of the inguinal ligament. L2 is the *genital* part, and supplies that part of the abdominal wall herniated into the scrotum for the descent of the testis (i.e. the spermatic cord). It is sensory to tunica vaginalis and the spermatic fasciae, and motor to cremaster muscle. It does not supply the testis and is unlikely to supply the scrotal skin, although often stated to do so. The genital branch is very small in the female, supplying the fascia on the round ligament in the inguinal canal and a small area of anterior labial skin.

Lateral femoral cutaneous nerve (L2, 3—posterior divisions, mostly L2, pp. 146 and 363)

The nerve is wholly sensory, to the iliac fascia and peritoneum of the iliac fossa, and to the lateral side of the thigh down to the knee. It emerges from the lateral

border of psoas (occasionally as a branch of the femoral nerve) and enters the thigh by passing through or under the lateral part of the inguinal ligament.

Femoral nerve (L2, 3, 4—posterior divisions, pp. 156 and 363)

The nerve issues from the lateral border of psoas and crosses the iliac fossa in the gutter between psoas and iliacus, deep to the iliac fascia. It *supplies iliacus* here, and then passes beneath the inguinal ligament lateral to the femoral sheath. Lying on iliacus, it breaks up at once into nine or ten branches. The lateral femoral circumflex artery runs through this leash, dividing the branches into ‘superficial’ and ‘deep’. There are four superficial branches (two cutaneous and two muscular). The deep branches supply quadriceps femoris (a branch for each vastus and two for rectus femoris) and include one cutaneous branch, the saphenous nerve.

Superficial branches. The nerve to *pectineus*, often double, runs behind the femoral sheath to reach the muscle. The nerve to *sartorius* often pierces the muscle and continues on as an intermediate femoral cutaneous nerve. The *intermediate femoral cutaneous nerve*, often piercing *sartorius*, supplies skin and fascia lata over the front of the thigh down to the knee. The *medial femoral cutaneous nerve* supplies the upper medial side of the thigh, and an anterior branch reaches the front of the knee; but the lower medial side of the thigh is supplied by the obturator nerve.

Deep branches. The nerve to *rectus femoris* is usually double, and the upper branch supplies also the *hip joint* (Hilton’s law, p. 12). The nerve to *vastus lateralis* runs down with the descending branch of the lateral femoral circumflex artery between rectus femoris and vastus intermedius. The nerve to *vastus intermedius* sinks into the anterior surface of that muscle. The nerve to *vastus medialis* enters the upper part of the subsartorial canal and sinks into the muscle. It is a very large nerve for, although the nerves to the two other vasti supply also a few fibres to the knee joint, this nerve carries most of the femoral branches to the knee.

The *saphenous nerve* gradually crosses the femoral artery in the subsartorial canal, gives some twigs to the subsartorial plexus, and runs on to emerge below the posterior border of *sartorius*. Here its *infrapatellar branch* pierces *sartorius* to run into the patellar plexus. The saphenous nerve, now cutaneous, supplies skin and periosteum over the subcutaneous surface of the tibia. It runs with the great saphenous vein in front of the medial malleolus and ends on the medial side of the foot just short of the big toe.

Obturator nerve (L2, 3, 4—anterior divisions, pp. 165 and 398)

Coming out of the medial side of psoas the nerve lies on the ala of the sacrum lateral to the lumbosacral trunk. It slants down to the side wall of the pelvis between the origin of the internal iliac artery and the ilium. From the angle between external and internal iliac vessels it runs straight to the obturator foramen, supplying the parietal peritoneum of the side wall of the pelvis (in the female the ovary lies here). In the obturator canal it splits into anterior and posterior divisions.

The **posterior division** supplies obturator externus, then pierces the upper border of that muscle and runs into the thigh deep to adductor brevis. It runs down on adductor magnus, whose pubic part it supplies (the ischial part of adductor magnus is supplied by the sciatic nerve). A slender branch accompanies the femoral artery into the popliteal fossa to supply the knee joint.

The **anterior division** passes over obturator externus and, emerging into the thigh, it supplies the hip joint. It runs down over adductor brevis, deep to pectineus and adductor longus. It supplies these two adductors and often helps the femoral nerve to supply pectineus. It also supplies gracilis. It supplies the lower medial side of the thigh by a cutaneous branch which runs through the subsartorial plexus.

The accessory obturator nerve (p. 397) supplies pectineus.

SACRAL PLEXUS

This is a flat, triangular formation on the front of piriformis muscle (p. 397). It is formed out of the lumbosacral trunk (L4, 5) and the upper four sacral nerves (Fig. 5.71). Its constituent nerves divide into anterior and posterior divisions. Its branches total a round dozen, six from the nerves before they divide, and three each from the anterior and posterior divisions.

The six branches from the main nerves all come from sacral segments and all have the initial 'P'.

Branches of the anterior rami

- S1, 2—Nerves to piriformis
- S2, 3—Perforating cutaneous
- S2, 3—Posterior femoral cutaneous
- S2, 3, 4—Pelvic splanchnic nerves
- S2, 3, 4—Pudendal
- S4—Perineal branch

The **nerves to piriformis** (S1, 2; p. 398) are twigs

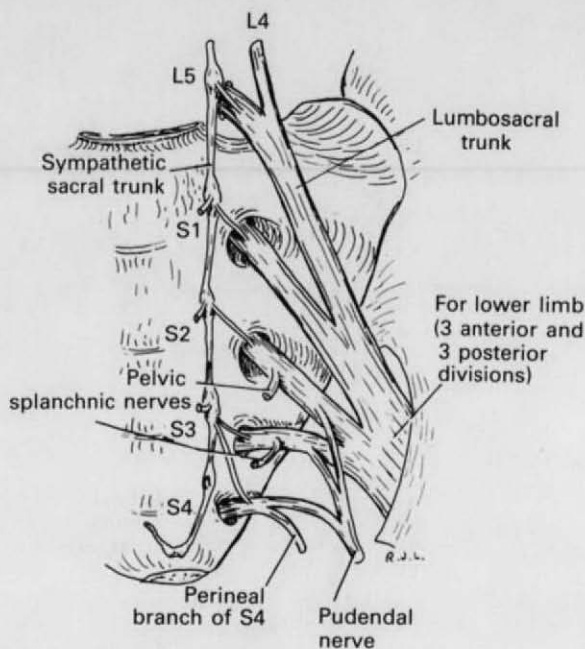


Fig. 5.71 Left sacral plexus. The branches from its anterior surface (three Ps) are shown.

that pass back from the upper sacral nerves into the muscle.

The **perforating cutaneous nerve** (S2, 3; p. 398) pierces the sacrotuberous ligament and the fibres of gluteus maximus that arise there, and supplies a small area of skin on the lower medial side of the buttock.

The **posterior femoral cutaneous nerve** (S2, 3; pp. 165 and 398) has a wide distribution. It runs down below piriformis on the sciatic nerve. At the lower border of gluteus maximus it becomes cutaneous, but is unique in that it remains beneath the deep fascia. It runs down the posterior midline beneath the fascia as far as the lower ends of the gastrocnemius bellies. It supplies a strip of deep fascia and skin, between anterior and posterior axial lines, from the buttock to the midcalf by a series of *perforating branches*, each of which pierces the deep fascia separately.

Branches. A *gluteal branch* winds around gluteus maximus to supply skin over the convexity of the buttock. The *perineal branch* winds around the hamstrings and gracilis origins and pierces the fascia lata at the medial convexity of the upper thigh. It supplies the lateral part of the posterior two-thirds of the scrotum (labium majus).

The **pelvic splanchnic nerves** (S2, 3, 4; pp. 33 and 398) constitute the sacral parasympathetic outflow, and the fibres join the inferior hypogastric plexus. They are

motor to the bladder (inhibitory to the internal sphincter) and to the large intestine from the splenic flexure downwards, and cause penile (clitoral) erection. Their afferent fibres include those for distension and pain from the bladder, lower cervix, lower colon and rectum. Referred pain may be felt in the distribution of the posterior femoral cutaneous nerve.

The **pudendal nerve** (S2, 3, 4; pp. 398 and 411) runs down and curls around the coccygeus muscle (whose gluteal surface is the sacrospinous ligament) and enters the pudendal canal. It is the nerve of the pelvic floor and perineum.

Branches. The *inferior rectal nerve* arches through the fat of the ischioanal fossa and its branches run alongside the anal canal to reach perianal skin. It is motor to the external anal sphincter (but not to levator ani).

The *perineal nerve* is a terminal branch of the pudendal. It runs forward superficial to the perineal membrane and breaks up to supply skin of the posterior two-thirds of the scrotum (labium majus) and the mucous membrane of the urethra (labia minora). It is motor to the muscles of the urogenital triangle, namely, ischiocavernosus, bulbospongiosus, superficial and deep transversus perinei and the sphincter urethrae. The sphincter urethrae branch runs above the perineal membrane into the deep perineal pouch; this branch is also sensory to the membranous (or female) urethra.

The *dorsal nerve* of the penis (clitoris) is the other terminal branch of the pudendal. It runs in the forward prolongation of the ischioanal fossa into the deep perineal pouch, deep to the perineal membrane, which it pierces just below the symphysis pubis. It runs forward to supply the skin of the whole penis (clitoris) except on the dorsum just at the root (ilioinguinal nerve).

The **perineal branch of S4**, probably accompanied by branches from S3, supplies levator ani on its upper surface, including the puborectalis part (p. 376). Passing between levator ani and coccygeus (which it also supplies), it enters the ischioanal fossa and runs down to reach the skin of the anal margin. Sympathetic fibres that hitch-hike along it reach the dartos muscle.

Branches of the anterior divisions of the anterior rami

L4, 5, S1—Nerve to quadratus femoris
L5, S1, 2—Nerve to obturator internus
L4, 5, S1, 2, 3—Tibial part of the sciatic

The **nerve to quadratus femoris** (L4, 5, S1; p. 165) (with the same root values as the superior gluteal nerve)

lies on the ischium deep to the sciatic nerve and, continuing in contact with the bone, runs down deep to obturator internus to sink into the deep surface of quadratus femoris. It supplies also the inferior gemellus and, exemplifying Hilton's Law, gives a branch to the hip joint.

The **nerve to obturator internus** (L5, S1, 2; p. 165) (with the same root values as the inferior gluteal nerve) passes below piriformis, curls around the base of the ischial spine and sinks into obturator internus. It supplies also the superior gemellus.

The **tibial part of the sciatic nerve** is formed from all five divisions (L4, 5, S1, 2, 3) (see below).

Branches of the posterior divisions of the anterior rami

L4, 5, S1—Superior gluteal
L5, S1, 2—Inferior gluteal
L4, 5, S1, 2—Common peroneal part of sciatic

The **superior gluteal nerve** (L4, 5, S1; p. 164) passes back around the great sciatic notch *above* piriformis, runs in the plane between glutei medius and minimus, supplies both, and ends in the tensor fasciae latae. It supplies no skin.

The **inferior gluteal nerve** (L5, S1, 2; p. 164) passes back *below* piriformis and sinks into the deep surface of gluteus maximus, rather on its medial side. It supplies no skin.

The **common peroneal (fibular) part** of the **sciatic nerve** is formed from only four posterior divisions (L4, 5, S1, 2). It joins the tibial in the pelvis and the sciatic nerve so formed lies on the ischium at the lower border of piriformis. If fusion fails to occur, the common peroneal nerve pierces piriformis.

Sciatic nerve (L4, 5, S1, 2, 3; pp. 165 and 172)

This is the true nerve of the lower limb; the adductor and extensor compartments of the thigh and the skin over the tibia (muscle and skin 'borrowed from the trunk') are supplied from the lumbar plexus by the obturator and femoral nerves. The main trunk of the sciatic nerve supplies the hamstring compartment and then separates into the tibial and common peroneal nerves. The tibial nerve supplies the flexor part of the calf and the sole of the foot around to the toenails. The common peroneal nerve supplies the extensor and peroneal compartments of the leg and the dorsum of the foot.

The **sciatic nerve** is formed at the lower margin of piriformis (p. 165) by union of the tibial and common

peroneal parts and emerges into the buttock lying on the ischium. The nerve to quadratus femoris is deep to it and the posterior femoral cutaneous nerve lies superficial. The sciatic nerve, midway between the greater trochanter and the ischial tuberosity, passes vertically downwards into the hamstring compartment (p. 172). It lies on obturator internus and gemelli, quadratus femoris and then on adductor magnus. It is overlaid by the long head of biceps. It lies a finger's breadth lateral to the flat tendon of semimembranosus. It divides, usually at the upper angle of the popliteal fossa, into the tibial and common peroneal nerves.

Branches. Motor branches supply all three hamstrings and the ischial fibres of adductor magnus. These last, as well as those for the long head of biceps and the two 'semi-' muscles, are from the tibial part, but the branch to the short head of biceps comes from the common peroneal part (p. 171).

Common peroneal (fibular) nerve (L4, 5, S1, 2; pp. 173 and 398)

This enters the apex of the popliteal fossa and runs alongside the biceps tendon just beneath the deep fascia (p. 173). It lies on the fat of the fossa and crosses plantaris, the lateral head of gastrocnemius, the popliteus tendon inside the kneejoint capsule and the fibular origin of soleus. It then sinks into the upper fibres of peroneus longus and divides into two terminal branches, the deep and superficial peroneal (fibular) nerves. It can be palpated in almost the whole of its course, but especially where it lies on the neck of the fibula, for here it can be rolled on the bone, where it is the nerve most commonly injured in the lower limb (p. 214).

The common peroneal nerve itself supplies no muscles, for it is the nerve of the extensor compartment, and the popliteal fossa through which it runs contains only flexor compartment muscles.

Two articular branches, the *upper and lower lateral genicular nerves*, supply the knee joint.

There are three cutaneous branches. The *peroneal communicating nerve* joins the sural nerve below the gastrocnemius heads. The *lateral cutaneous nerve of the calf* pierces the deep fascia as the nerve lies on soleus and supplies skin and deep fascia over the upper half of the peroneal compartment. The third cutaneous branch, called *recurrent genicular*, is unimportant. It supplies the superior tibiofibular joint, a few fibres of tibialis anterior, and a little skin over the patellar ligament.

The **deep peroneal nerve** is formed in the

substance of peroneus longus (p. 188), spirals down over the fibula deep to extensor digitorum longus and reaches the interosseous membrane. It runs down lateral to the vessels, crosses the lower end of the tibia and the dorsum of the foot, and ends by supplying the skin of the first interdigital cleft.

It supplies the muscles of the extensor compartment of the leg: extensor digitorum longus, tibialis anterior, extensor hallucis longus and peroneus tertius. On the dorsum of the foot it gives a lateral branch which passes deep to extensor digitorum brevis and supplies that muscle. It is beneath the deep fascia, and supplies periosteum and ligaments of the tibia and the dorsum of the foot.

The **superficial peroneal nerve** is formed in the substance of peroneus longus and runs down in the muscle, emerging from its anterior border about a third of the way down the leg (pp. 191 and 190). It supplies peroneus longus and brevis, then perforates the fascia over them about halfway down the leg. It supplies the skin over the peronei and extensor muscles in the lower half of the leg. Above the ankle it divides into a medial and a lateral branch which diverge only narrowly. They supply skin and deep fascia on the dorsum of the foot (the deep peroneal nerve supplies the underlying bones). The medial branch breaks up to supply the medial side of the big toe and the second interdigital cleft, while the lateral branch breaks up to supply the third and fourth clefts.

Tibial nerve (L4, 5, S1, 2, 3; pp. 174 and 196)

The nerve enters the apex of the popliteal fossa and, in the midline of the limb, passes vertically down deep to the heads of gastrocnemius behind the knee joint and across the popliteus muscle, to run beneath the fibrous arch in soleus.

Branches in the popliteal fossa. Three *geniculate nerves*, upper and lower medial and a middle, accompany the arteries and supply the knee joint. *Five muscular branches* supply the muscles of the fossa: plantaris, both heads of gastrocnemius, soleus and popliteus. The last-named branch recurves around the lower border of the muscle to enter its deep (i.e. anterior) surface. A single cutaneous branch, the *sural nerve*, lies in the groove between the two heads of gastrocnemius and pierces the deep fascia halfway down the leg. Here it is joined by the peroneal communicating nerve. The sural nerve runs down alongside the small saphenous vein behind the lateral malleolus and ends on the lateral side of the little toe.

From the fibrous arch the nerve runs down with the

posterior tibial vessels beneath the soleus muscle. The neurovascular bundle lies in the groove between the bellies of flexor hallucis longus and flexor digitorum longus. Behind the medial malleolus, beneath the flexor retinaculum, the nerve divides, distal and superficial to the vessels, into its terminal medial and lateral plantar branches.

Branches in the calf. Four muscular branches supply soleus, tibialis posterior and the flexors hallucis and digitorum longus. The nerve also supplies periosteum on the flexor surfaces of tibia and fibula. *Medial*

calcaneal branches pierce the flexor retinaculum and supply the weight-bearing skin of the heel.

The *medial* and *lateral plantar nerves* (p. 203) correspond approximately to the median and ulnar nerves in the hand as far as skin and muscle supplies are concerned. The medial plantar supplies the medial part of the sole and plantar surface of the medial three and a half digits, and innervates flexor digitorum brevis, abductor hallucis, flexor hallucis brevis and the first lumbrical, with the lateral plantar supplying the rest of the sole and the other small muscles of the foot.

6. Head and neck and spine

PART 1

GENERAL TOPOGRAPHY OF THE NECK

The first thoracic vertebra lies at the highest part of the sloping thoracic inlet. From its upper border rises the cervical spinal column, gently convex forwards, and supporting the skull. A mass of *extensor musculature* lies behind the vertebrae. It is supplied segmentally by posterior rami and supports the cervical spine and head. A much smaller amount of prevertebral *flexor musculature* lies in front of the vertebrae and, more laterally, is attached to the thoracic inlet and the scapula. It is supplied segmentally by anterior rami. This musculature comprises longus colli, rectus capitis anterior and rectus capitis lateralis, longus capitis, scalenus anterior, scalenus medius, scalenus posterior and levator scapulae. The whole mass, projecting but little in front of the cervical spine, lies flat from side to side behind the pharynx, and from here curves away posteriorly; it is covered over by the prevertebral fascia, which thus forms a vertical sheet passing from side to side across the central part of the neck.

Projecting forwards and downwards from the base of the skull is the *face*, which thus lies in front of the upper part of the prevertebral fascia. The hard palate lies on a level with the anterior arch of the atlas (C1 vertebra), the lower border of the mandible lies between C2 and 3 vertebrae. Suspended from the back of the face is the pharynx, which extends below to the level of the cricoid cartilage (C6) and then continues on as the oesophagus.

In front of the sheet of prevertebral fascia lie the *viscera of the neck* — pharynx and oesophagus, larynx and trachea in front of these and, on each side, the carotid sheaths, lying on each side of the pharynx. Lying above the larynx is the hyoid bone. It is connected to the mandible by the mylohyoid muscles, which form the upper limit of the anterior part of the

neck. Mylohyoid separates the mouth from the neck. The hyoid bone and larynx are suspended by muscles from the skull. Inferiorly they are connected by muscles to the sternum and the scapula; beneath these muscles the thyroid gland, enclosed in the pretracheal fascia, lies alongside the respiratory canal. The anterior part of the neck extends no higher than the mandible, being limited by the mylohyoid, above this level the face extends to the base of the skull. Further back the neck extends as high as the base of the skull; on each side of the pharynx is a carotid sheath, with the cervical sympathetic trunk behind it. Emerging into the neck are the ninth, tenth, eleventh and twelfth cranial nerves. Finally surrounding the whole neck is a collar of fascia, the investing layer of deep cervical fascia, which contains the trapezius and sternocleidomastoid muscles.

DEEP CERVICAL FASCIA

The **deep cervical fascia** consists of four parts: the investing layer, pretracheal fascia, prevertebral fascia, and the carotid sheath.

Investing layer

This fascia, comparable in every way to the deep fascia that underlies the subcutaneous fat in the limbs and elsewhere, surrounds the neck like a collar (Fig. 6.1). It splits around sternocleidomastoid and trapezius with a layer adherent to the superficial and deep surfaces of each of them. Posteriorly it meets the ligamentum nuchae, from which the cervical part of trapezius arises. The fascia is attached to the hyoid bone, hence the chin and Adam's apple of man in profile; there is no 'dewlap' as in cattle. On the base of the skull, the attachments of trapezius and sternocleidomastoid extend from the external occipital protuberance in a curve along the superior nuchal line to the tip of the mastoid process. The investing layer enclosing both muscles is attached to the skull over the whole extent of this line; in the

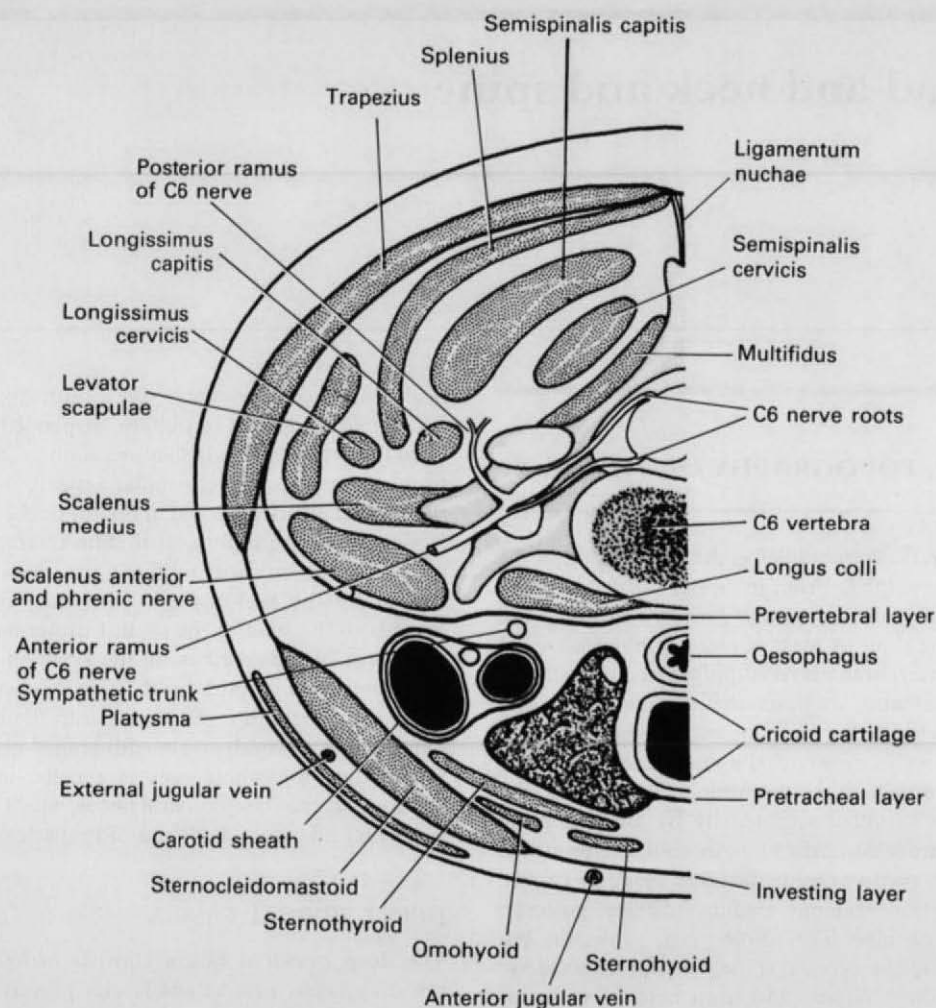


Fig. 6.1 Deep cervical fascia of one half of the neck, showing its four components; the investing, pretracheal and prevertebral layers and the carotid sheath.

front of the neck it is attached to the lower border of the mandible, from chin to angle on each side.

Between the angle of the mandible and the tip of the mastoid process the investing layer splits to form a capsule for the parotid gland. The superficial part of the capsule, attached above to the zygomatic arch, is thick and forms the *parotid fascia*. The deep part extending from the styloid process to the angle of the mandible is thickened as the *stylomandibular ligament*. A further thickening has been described between the angle of the mandible and the anterior border of sternocleidomastoid, sometimes called the *mandibulostylohyoid ligament* because it can be traced from the angle to the lower end of the stylohyoid ligament.

The lower attachment of the investing layer is to the

pectoral girdle. It is attached to the spine of the scapula and the lateral flat part of the clavicle with the trapezius muscle, and to the clavicle and sternum with the sternocleidomastoid. In the intervals between these muscles, it is attached to both clavicles and to the jugular notch by two layers into which it splits a short distance above them. The layers are attached to the *anterior and posterior* borders of the jugular notch, enclosing between them the **suprasternal space** in which the anterior jugular veins angle laterally to pass behind the sternocleidomastoids; the veins are often joined in the space by an anastomatic arch. Of the two layers that adhere to the middle third of the clavicle (between sternocleidomastoid and trapezius) the deeper splits around the inferior belly of the omohyoid, forming a fascial sling

which binds the muscle down to the clavicle (Fig. 2.3, p. 56). The two layers represent, above the clavicle, the two layers of clavipectoral fascia that enclose the subclavius muscle. They are pierced by the external jugular vein.

The relations of the veins of the face and neck to the investing layer are dealt with on page 452.

Prevertebral fascia

This is a firm, tough membrane that lies in front of the prevertebral muscles (Fig. 6.1). It extends from the base of the skull in front of the longus capitis and rectus capitis lateralis downwards to the lower limit of the longus colli muscle (body of T3 vertebra). It extends sideways across the scalenus anterior, scalenus medius and levator scapulae muscles (Fig. 6.6), getting thinner further out and finally fading out of existence well under cover of the anterior border of trapezius. In the posterior triangle of the neck it covers the muscles that floor the triangle, and, since it crosses in front of the anterior tubercles of the cervical transverse processes, all the cervical nerve roots (and thus the cervical plexus and trunks of the brachial plexus) lie deep to it. The lymph nodes of the posterior triangle and the accessory nerve lie superficial to it. It has also the third part of the subclavian artery (not the vein) deep to it; it becomes prolonged over the artery below the clavicle as the **axillary sheath**. It does not invest the subclavian or axillary vein; these lie in loose areolar tissue anterior to it, free to dilate during times of increased venous return from the upper limb. The fascia is pierced by the four cutaneous branches of the cervical plexus (great auricular, lesser occipital, transverse cervical and supraclavicular nerves). The purpose of the prevertebral fascia is to provide a fixed basis on which the pharynx, oesophagus and carotid sheaths can glide during neck movements and swallowing, undisturbed by any movements of the prevertebral muscles.

Pretracheal fascia

Like the other fasciae of the neck, this (Fig. 6.1) forms a layer between sliding surfaces. It lies deep to the infrahyoid strap muscles (sternothyroid, sternohyoid and omohyoid) so that its upward attachment is limited by the respective attachments of those muscles, namely, the hyoid bone at the midline and the oblique line of the thyroid cartilage more laterally. It splits to enclose the thyroid gland, to which it is not adherent except between the isthmus and second, third and fourth rings of the trachea. The thymus lies behind it, and aberrant inferior parathyroid glands (developed from the same

branchial pouch as the thymus) migrate down behind it. It is pierced by the thyroid vessels. Laterally, it fuses with the front of the carotid sheath on the deep surface of the sternocleidomastoid and inferiorly it passes behind the brachiocephalic veins to blend with the adventitia of the arch of the aorta and the fibrous pericardium. Comparable to the prevertebral fascia, the pretracheal fascia provides a slippery surface for up and down gliding of the trachea during swallowing and neck movements.

Carotid sheath

This is not a fascia in the sense of a demonstrable membranous layer, but consists of a feltwork of areolar tissue that surrounds the carotid arteries (common and internal), internal jugular vein and the vagus nerve (Fig. 6.1). It is thin where it overlies the internal jugular vein; this is to be expected, for the vein must be free to dilate during increased bloodflow. The sheath is attached to the base of the skull at the margins of the carotid canal, and is continued downwards along the vessels to the aortic arch. In front the lower part of the sheath is firmly attached to the deep surface of the sternocleidomastoid and along this line the pretracheal fascia blends with it. Behind the carotid sheath there is a minimum of loose areolar tissue between it and the prevertebral fascia — not enough to limit the spread of infection. In this tenuous tissue the cervical sympathetic trunk lies, attached to the front of the prevertebral fascia (Fig. 6.6). It is described further on pages 434 and 462.

TISSUE SPACES OF THE NECK

The so-called **tissue spaces** of the neck are potential spaces with loose connective tissue which can become expanded when invaded by infection. Since the advent of antibiotics they have become less significant than in the past, but those that remain of most importance clinically are the prevertebral, retropharyngeal, parapharyngeal and submandibular spaces.

Behind the prevertebral fascia is the closed **prevertebral space** from which the only escape can be made by a perforation in the fascia. For example, an abscess from a cervical vertebra can lift the prevertebral fascia as far as the third thoracic body, but can extend no lower unless the fascia gives way. Immediately in front of the prevertebral fascia is a space that extends from the base of the skull to the diaphragm (Fig. 4.11, p. 255). Its upper part is the **retropharyngeal space**; and below this the space extends behind the oesophagus through the superior into the posterior mediastinum. In the

neck the retropharyngeal space lies between the prevertebral fascia and the buccopharyngeal fascia on the outer surface of the pharynx (p. 486). Infection in this space (e.g. in infants from infected lymph nodes that lie here) may pass behind the carotid sheath into the posterior triangle. Pathological walling off usually prevents downward spread into the mediastinum, although there is no anatomical barrier to such spread. The space may be said to continue laterally into a **parapharyngeal space** at the side of the pharynx; this space is bounded laterally by the pterygoid muscles and the parotid sheath. In the upper part of the neck there is further continuation anteriorly into the **submandibular space** which extends above the investing layer of fascia between the hyoid bone and the mandible to the mucous membrane of the floor of the mouth. It contains the mylohyoid muscle with the sublingual gland above it and the submandibular gland hooking round its posterior border. Infection here produces the cellulitis known as Ludwig's angina (p. 436).

PART 2

TRIANGLES OF THE NECK

To assist the description of the topographical anatomy of the neck, each side is divided into *anterior* and *posterior triangles* by the obliquely placed sternocleidomastoid muscle (Figs 6.2 and 6.4). The **posterior triangle** lies between the posterior border of sternocleidomastoid, the anterior border of trapezius and the clavicle, and the anterior triangle between the anterior border of sternocleidomastoid, the lower border of the mandible and the midline. The **anterior triangle** can be subdivided into submental, digastric, carotid and muscular triangles. None of these has any meaning except to divide a complicated area into small packages which many find a helpful aid to memory (see p. 439).

Sternocleidomastoid

This prominent neck landmark (Figs 6.2 and 6.4) is still commonly known by its older name of sternomastoid. The two heads of origin below spring from the manubrium and clavicle respectively; that from the manubrium is a rounded tendon, that from the clavicle a thick fleshy mass. A triangular interval exists between the two above the sternoclavicular joint, and the *lower end of the internal jugular vein lies here*, where it can be entered by needle or catheter. The manubrial tendon is attached to the front of the bone below the jugular

notch. From this tendon a broad fleshy belly develops which passes upwards to be inserted into a curved line extending from the tip of the mastoid process to the superior nuchal line of the occipital bone. Thus one could speak of two parts of the muscle here — sternomastoid and sterno-occipitalis, though the two parts are intimately blended. The posterior fibres of the clavicular head are inserted into the superior nuchal line medial to and in line with the sterno-occipitalis fibres. This part of the muscle could be called cleido-occipitalis, and it forms with the other two a continuous sheet on the surface of the muscle. The remaining fibres (cleidomastoid) lie deep to these. Between this part of the muscle and the rest the accessory nerve enters the muscle and runs down within it to emerge into the posterior triangle about halfway down the posterior border of the muscle.

Sternocleidomastoid is enclosed within a sheath of the investing layer of deep cervical fascia, which splits to surround it (Fig. 6.1). The attachment more anteriorly of this fascia to the hyoid bone draws the muscle forward in a gentle convexity that is very noticeable when the head is rotated.

The muscle separates the anterior and posterior triangles of the neck. When the triangles have been studied there remains a wide strip of territory deep to the muscle. In general one can say that deep to the upper half of it lies the cervical plexus (p. 426), and deep to its lower part lies the common carotid artery and carotid sheath (p. 434) overlying scalenus anterior.

The blood supply of the muscle is from branches of the occipital and superior thyroid arteries.

Nerve supply. By the spinal part of the accessory nerve, C1–6 but mostly C2 and 3, from a branch which leaves it proximal to its point of entry into the muscle. The anterior horn cells of the segments concerned are innervated by the cerebral cortex of their own side (but those supplying trapezius—p. 57—receive the usual contralateral innervation). The reason is that when, for example, the *left* upper limb muscles (including trapezius) are being used and the head is turned to that side to see what is going on, it is the *right* sternocleidomastoid that is turning the head to the left; the same (right) cortex controls all the muscles. Branches from the cervical plexus (C2, 3) also enter the muscle but these are only proprioceptive.

Action. Contraction of one muscle produces the 'wry neck' position with the ear approaching the tip of the shoulder and the chin rotating to the opposite side. (Splenius capitis of the opposite side produces the same result.) If the opposite abducting muscles contract (such as scalenus medius and semispinalis cervicis) the neck is held vertical and simple rotation of the head

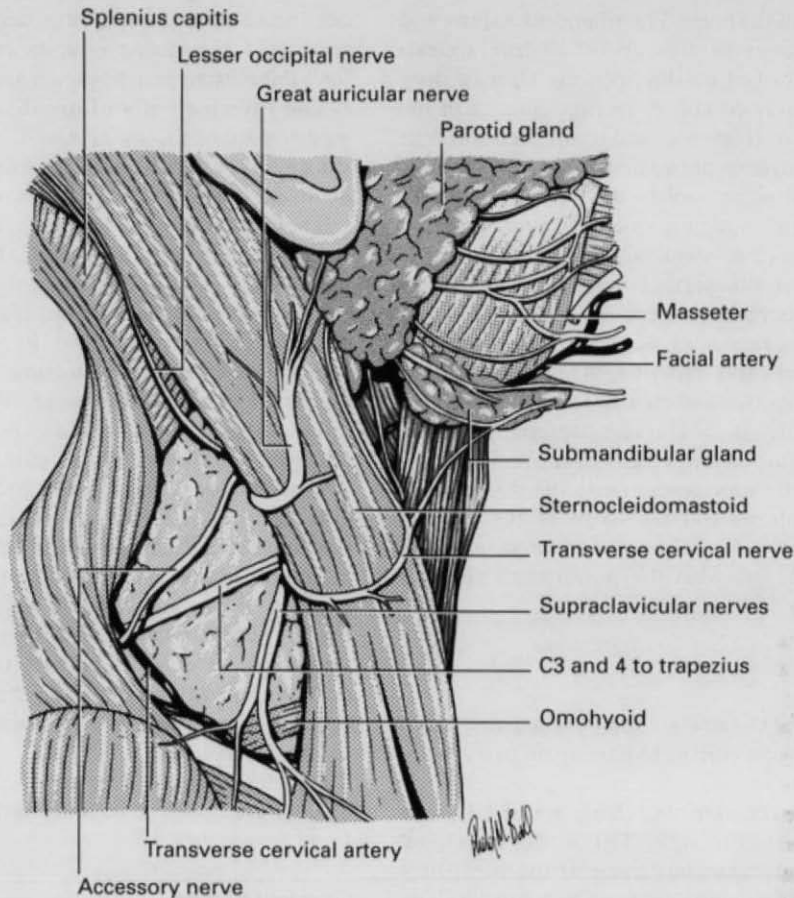


Fig. 6.2 Superficial dissection of the right posterior triangle. The fat in the lower part of the triangle obscures the intact prevertebral fascia.

results. Sternocleidomastoid is the principal rotator of the lateral atlantoaxial joint, and in turning the face towards the opposite side the muscle can easily be seen and felt.

The action of both muscles contracting simultaneously is more complex. The result depends in part on the previous position of the head, and above all upon what other muscles are contracting at the same time. The posterior fibres pass up behind the lateral atlanto-occipital joints, which they therefore extend. The most anterior fibres lie just in front of these joints, so this part of the muscle flexes the skull on the atlas. However, the chief purpose of the muscle, starting with the head in the normal position (face vertical, gaze horizontal) is to protract the head — to move the face forwards while keeping it vertical and maintaining a horizontal gaze, as in peering over someone's shoulder in a crowd. Note that this action is a combination of flexion of the cervical spine and extension of the atlanto-occipital

joints simultaneously. It cannot be overemphasized that the sternocleidomastoids seldom contract alone, and their action must always be considered in association with other groups. They are essentially antagonists to the extensor muscles behind the vertebrae, but since they are not attached to the vertebral column and only to the movable head, they must exert a powerful action to the atlanto-occipital joints in addition to flexing the cervical spine.

Test. The face is turned to the opposite side against resistance and the muscle palpated.

POSTERIOR TRIANGLE

This is an area enclosed between the sternocleidomastoid and trapezius muscles. Its apex lies high up at the *back* of the skull on the superior nuchal line. Its base is *in front* at the root of the neck and consists of the part of the clavicle lying between the two muscles, generally

the middle third of the bone. The triangle is a spiral and therefore illustrations tend to distort its true appearance. Its *roof* is formed by the investing layer of deep cervical fascia described above. Its *floor* consists of the prevertebral fascia (Figs 6.2 and 6.6). Beneath this fascia may be seen, from above downwards, portions of the following muscles: splenius, levator scapulae, scalenus posterior, scalenus medius, and scalenus anterior, while in the lateral angle just beyond the border of the first rib, part of the first digitation of serratus anterior is visible, especially if the shoulder be depressed. At the very apex of the triangle, between sternocleidomastoid and trapezius, the upper border of splenius (p. 546) is often low enough to expose a little of semispinalis capitis (p. 544). The prevertebral fascia plasters down upon the lower parts of the scalenes and levator scapulae the subclavian artery, the three trunks of the brachial plexus and the loops of the cervical plexus. In operations on the posterior triangle all these structures are safe provided the prevertebral fascia is left intact.

Contents

At the very apex of the triangle the occipital artery and greater occipital nerve emerge to pass up on to the scalp (p. 453).

Lying between the roof and floor are the **lymph nodes** of the posterior triangle. Two or three occipital nodes lie in the subcutaneous tissue at the apex; they become enlarged in scalp infections and rubella. The nodes are most numerous above the clavicle, constituting the supraclavicular nodes; they are really outlying members of the lower group of deep cervical nodes (p. 522).

The **accessory nerve** emerges from sternocleidomastoid about halfway down its posterior border, and passes almost vertically downwards overlying levator scapulae and embedded within the fascia of the roof of the triangle, to disappear beneath the anterior border of trapezius 5 cm above the clavicle (Fig. 6.2). It is thus particularly liable to injury in operations involving the removal of lymph nodes. The *surface marking* of the nerve can be demonstrated by first palpating the transverse process of the atlas (in front of the mastoid process). From this point a line drawn to the anterior border of trapezius 5 cm above the clavicle indicates the course of the nerve through sternocleidomastoid and the triangle.

The cutaneous branches of the **cervical plexus** pierce the investing fascia at the posterior border of sternocleidomastoid. The cervical branches to trapezius pass across the fascial floor of the triangle. They must

not be confused with the accessory nerve which emerges *from within the substance* of sternocleidomastoid; the plexus branches are *behind* the muscle.

The **inferior belly of omohyoid** crosses the lower medial part of the triangle and is kept in place by its sling of investing fascia. A thin muscle belly must not be confused with the suprascapular nerve or vessels.

The **transverse cervical** and **suprascapular** vessels are in the lower part of the triangle just above the clavicle. The third part of the **subclavian artery** (p. 444) is also classified among the contents of the triangle but is very low down. Its *pulsation* can be felt by pressing downwards behind the clavicle at the lateral border of sternocleidomastoid. The subclavian vein is lower still and is not included in the triangle, but the **external jugular vein** slips into the anterior corner of the triangle on its way to the subclavian.

In the floor of the posterior triangle, levator scapulae, described with the muscles of the pectoral girdle (p. 60), is usually split longitudinally into two ribbons of muscle. The accessory nerve lies upon it, separated by the prevertebral fascia. The transverse cervical artery divides at its anterior border, the ascending branch running up to the muscle, the descending branch running down deep to it, in company with the dorsal scapular nerve (see p. 445).

Scalenus posterior, scalenus medius and scalenus anterior are described with the root of the neck (p. 442).

Cervical plexus

The **cervical plexus** (Fig. 6.3) is formed by simple loops between the anterior rami of the upper four cervical nerves, after each has received a grey ramus from the superior cervical ganglion. It lies in series with the brachial plexus, on the scalenus medius, plastered down beneath the prevertebral fascia. It is covered by the upper part of sternocleidomastoid, and does not lie actually *in* the posterior triangle.

Muscular branches. Muscular branches are given off segmentally to the prevertebral muscles (longus capitis, longus colli and the scalenes). Other muscular branches are:

(1) A loop from C1 to the hypoglossal nerve, by which the fibres are carried to its meningeal branch and the superior root of the ansa cervicalis, the former 'descendens hypoglossi' (infrahyoid muscles) and the nerves to thyrohyoid and geniohyoid.

(2) Branches from C2 and 3 to sternocleidomastoid, and from C3 and 4 to trapezius (Fig. 6.2). These fibres are proprioceptive, all the motor fibres to the muscles being in the accessory nerve but there is evidence that

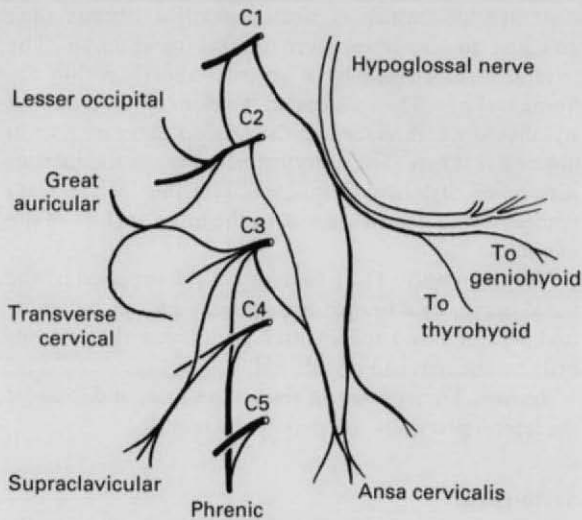


Fig. 6.3 Left cervical plexus.

occasionally the whole of trapezius is not paralysed when the accessory nerve is damaged, in which case at least some of the cervical fibres are presumably motor.

(3) The **inferior root of the ansa cervicalis** (formerly called 'descendens cervicalis') is formed by union of a branch each from C2 and C3. The nerve spirals around the lateral side of the internal jugular vein and descends to join the superior root (C1) at the ansa (p. 434).

(4) The **phrenic nerve** is formed mainly from C4 with unimportant contributions from C3 and C5 and runs down vertically over the obliquity of the scalenus anterior muscle, passing from lateral to medial borders, beneath the prevertebral fascia, lateral to the ascending cervical branch of the inferior thyroid artery. It passes behind the subclavian vein into the mediastinum (p. 261). It may be joined below the vein by a branch (the **accessory phrenic nerve**) from the nerve to subclavius. It is not uncommon for the phrenic nerve to descend in front of the subclavian vein. Rarely it may penetrate the vein. This is understood by recalling that the vein forms by a coalescence of a rich venous plexus in the embryo. The phrenic nerve is one of the most important in the body, being the sole motor supply to its own half of the diaphragm (p. 250), and it also has an extensive afferent distribution, not only to the diaphragm but to the pericardium, pleura and peritoneum (pp. 265, 281 and 318).

Cutaneous branches. Cutaneous branches of the plexus supply the front and sides of the neck (Fig. 6.2).

The **lesser occipital nerve** (C2) is a slender branch that hooks around the accessory nerve and runs up

along the posterior border of sternocleidomastoid to supply the posterior part of the neck up to the superior nuchal line (i.e. over the upper part of sternocleidomastoid), and behind the auricle. It may overlap to the tip of the auricle.

The **great auricular nerve** (C2, 3, mostly 2) is much more important. A large trunk passing vertically upwards over sternocleidomastoid, it is distributed to an area of skin on the face over the angle of the mandible and the parotid gland and to the parotid fascia as well as to the auricle. It supplies the skin of the auricle over the whole of its cranial surface and on the lower part of its lateral surface below the external acoustic meatus, and skin over the mastoid region. Branches passing deep to the parotid gland supply the deep layer of the parotid fascia. The nerve has a curious propensity to become palpably and visibly thickened in tuberculoid leprosy.

The **transverse cervical nerve** (formerly the anterior cutaneous nerve of the neck) (C2, 3) emerges as a single trunk behind the posterior border of sternocleidomastoid, and quickly breaks up into a number of slender twigs that innervate the skin in the midline of the neck from chin to sternum. Interruption of the main trunk thus produces a very elongated area of anaesthesia. The nerve is some distance from the transverse cervical artery, which is just above the clavicle.

The **supraclavicular nerve** (C3, 4, but mostly 4) emerges in common with the other three at the posterior border of sternomastoid and soon divides into three branches or groups of branches. They are distributed in three main groups. The medial group supply the skin as far down as the sternal angle and the sternoclavicular joint. The intermediate group proper pass anterior to (occasionally through) the clavicle and supply skin as far down as the anterior axial line. The lateral group pass not only across the acromion to the skin halfway down the deltoid muscle, but also over the posterior aspect of the shoulder to supply skin as far down as the spine of the scapula (posterior axial line: Fig. 1.11, p. 20).

Dermatomes of the neck

In addition to the cutaneous branches of the cervical plexus described above, which supply the anterior and lateral skin of the neck, the greater occipital and third occipital nerves from posterior rami of C2 and C3 respectively (p. 454) provide sensory fibres for the back of the neck (Fig. 6.13). The first cervical nerve does not supply any skin. C2 supplies most of the posterior part of the neck, extending into the occipital region of the scalp and forwards to the auricle and the face over the

angle of the mandible, C3 supplies the cylindrical part of the neck, C4 extends over the clavicular region across the top of the shoulder and down to the scapular spine (an area that supports the weight of a cape). There is much overlap between the boundary lines shown in the figure.

ANTERIOR TRIANGLE

As mentioned on page 424, the traditional subdivision of this area into several triangles is only useful in breaking it into smaller packages, and here they will only be referred to at the end of this section (p. 439) to provide localized summaries that can be useful aids to memory for practical and oral examinations, and for surgeons operating in these regions. The general area bounded by the lower border of the mandible and lying between the two sternocleidomastoid muscles is dealt with as a whole. It contains the viscera of the neck.

Beneath the investing layer of deep cervical fascia are two groups of longitudinal muscles that extend from the mandible to the sternum, and which are supplied segmentally by the anterior rami of the upper three cervical nerves. The hyoid bone, situated at the level of C3 vertebra, is an important landmark at the front and side of the neck, and provides attachments for (among others) the two groups of four muscles each (Fig. 8.15, p. 665). The *suprahyoid muscles* above the bone comprise digastric, stylohyoid, mylohyoid and geniohyoid; the mylohyoids of each side unite to form the floor of the mouth, with the digastrics and stylohyoids superficial and geniohyoids deep to them. The *infrahyoid group* below the bone are sternohyoid and omohyoid, lying side by side in the same plane, and more deeply a wider sheet of muscle attached to the thyroid cartilage and forming thyrohyoid and sternothyroid. The last four are commonly called the 'strap muscles' from their flat shape. All these muscles are in the same plane of the body wall musculature as rectus abdominis. One should picture the rectus sheet as extending from chin to pubic symphysis, supplied segmentally from C1 to T12 spinal nerves, but interrupted by the intervention of the thoracic cage. Remnants of the longitudinal strip sometimes lie over pectoralis major, forming rectus sternalis (Fig. 2.2, p. 55).

SUPRAHYOID MUSCLES

Digastric

This arises as the posterior belly, from the digastric notch on the medial surface of the mastoid process. The triangular fleshy belly tapers down to the interme-

diate tendon, which is held beneath a fibrous sling attached to the lesser horn of the hyoid bone. The tendon is lubricated by a synovial sheath within the fibrous sling. The bifurcated tendon of insertion of stylohyoid which embraces the tendon plays no part in holding it down. The anterior belly lies on the inferior surface of mylohyoid, and connects the intermediate tendon to the digastric fossa on the inner surface of the mandible.

Nerve supply. The posterior belly is supplied by the facial nerve, by a branch arising between the stylomastoid foramen and the parotid gland, and the anterior belly by the nerve to mylohyoid.

Action. To depress and retract the chin, and to assist the lateral pterygoid in opening the mouth.

Stylohyoid

This arises from the back of the styloid process, high up near the base of the skull, and slopes down along the upper border of digastric. Its lower end divides to embrace the digastric tendon and is inserted by two slips into the base of the greater horn of the hyoid bone.

Nerve supply. By the facial nerve, by a branch usually arising with that to the posterior belly of digastric.

Action. To retract and elevate the hyoid bone when swallowing.

Mylohyoid

The muscles of each side unite to make a thin sheet forming the 'diaphragm' of the floor of the mouth (Fig. 6.5). Each rises from the whole length of the mylohyoid line of its own side of the mandible as far back as the posterior surface of the third molar tooth. The two muscles slope downwards towards each other, and the posterior quarter of each is inserted into the anterior surface of the body of the hyoid bone. In front of this the anterior three-quarters of each interdigitate in a midline raphe which extends from the chin to the hyoid bone.

Nerve supply. By its own nerve, a branch of the inferior alveolar (from the mandibular division of the trigeminal nerve), which arises just before the parent nerve enters the mandibular foramen.

Action. It forms a mobile but stable floor of the mouth and supports the weight and thrust of the tongue. The two muscles together form a gutter; contraction makes the gutter more shallow, thus elevating the tongue and the hyoid bone as when swallowing or protruding the tongue (see p. 483).

Geniohyoid

This slender flat ribbon of muscle extends from the inferior mental spine (genial tubercle) of the mandible to the upper border of the body of the hyoid bone. The two muscles lie side by side between the mylohyoids and the base of the tongue (genioglossus), in the floor of the mouth (p. 484).

Nerve supply. By a branch from the hypoglossal nerve, but it consists of fibres from C1 nerve and not from the hypoglossal nucleus; it is not seen superficially in the neck because the mylohyoids have migrated below it.

Action. To protract and elevate the hyoid bone in swallowing, or if the hyoid is fixed, to depress the mandible.

INFRAHYOID MUSCLES

Sternohyoid

This flat strap of muscle extends from the lower border of the hyoid bone to the back of the sternoclavicular joint and adjoining parts of manubrium and clavicle. The two muscles lie edge to edge at the hyoid bone, but diverge from each other below; the Adam's apple projects through the space between them (Fig. 6.4).

Nerve supply. By a branch from the ansa cervicalis which enters the lower end of the muscle and runs up in its substance to supply it segmentally (C1, 2, 3 from above down). Tendinous intersections, occasionally present, indicate the segmental origin of the muscle from paravertebral myotomes (compare with rectus abdominis but see p. 298).

Omohyoid

This flat strap of muscle lies edge to edge with sternohyoid at its attachment to the lateral part of the inferior border of the hyoid bone (Fig. 6.4). As it descends it diverges somewhat from the sternohyoid and, passing beneath sternocleidomastoid, it comes to lie over the carotid sheath. Where it lies over the internal jugular vein, the muscle fibres are replaced by a flat tendon that slides readily on this structure; the tendon is a useful guide at operation to the underlying vein. A change of direction now occurs, and the inferior belly passes almost horizontally just above the level of the clavicle to pass back to its attachment to the transverse scapular ligament and a little of the upper border of the scapula. The intermediate tendon and supraclavicular portion of the muscle are bound down to the clavicle in a fascial sling derived from the deep layer of the investing layer of deep cervical fascia (Fig. 2.3, p. 56). The *development* of the

muscle is interesting. At first attached in the fetus to the medial end of the clavicle it is a longitudinal strip of muscle like the rest of the infrahyoid musculature. However, it migrates along the clavicle and finally reaches its adult attachment to the scapula. The process of migration may be arrested at any point.

Nerve supply. By the ansa cervicalis (C1, 2, 3 from above down).

Thyrohyoid

This is a broader and shorter muscle that lies under cover of the upper ends of sternohyoid and omohyoid. It arises beneath these two muscles from the greater horn of the hyoid bone, and is inserted into the oblique line of the thyroid cartilage, end to end with sternothyroid.

Nerve supply. By a branch of the hypoglossal nerve, but the fibres are all 'hitch-hiking' from C1 like the nerve to geniohyoid.

Sternothyroid

Broader than sternohyoid and lying deep to it (Fig. 6.4), this muscle is attached lower down than sternohyoid on the posterior surface of the manubrium; so low, in fact, that it is below the sternoclavicular joint and has no attachment to the clavicle. It extends laterally from the manubrium to the first costal cartilage. Its upper attachment is to the oblique line of the thyroid cartilage.

Nerve supply. By the ansa cervicalis (C2, 3).

Actions of the infrahyoid muscles

They are all depressors of the larynx. Sternothyroid acts directly on the thyroid cartilage, the others act indirectly via the hyoid bone. Depression of the larynx increases the volume of the resonating chambers during phonation and thus affects the quality of the voice. Probably a much more significant role of the infrahyoid muscles is to oppose the elevators of the larynx (mylohyoid, palatopharyngeus, stylopharyngeus, salpingopharyngeus, inferior constrictor), 'paying out rope' during contraction of the elevators; descent of the larynx after elevation is due at least partly to elastic recoil of the trachea. The infrahyoid muscles prevent ascent of the hyoid bone when the digastric is in action (p. 525). A contracting thyrohyoid approximates the thyroid cartilage and hyoid bone. Which moves the more depends on what other muscles are in action at the time. When the head is rotated to one side, the opposite omohyoid is straightened, and can exert a more direct downward pull on the hyoid bone (Fig. 6.58, p. 524).

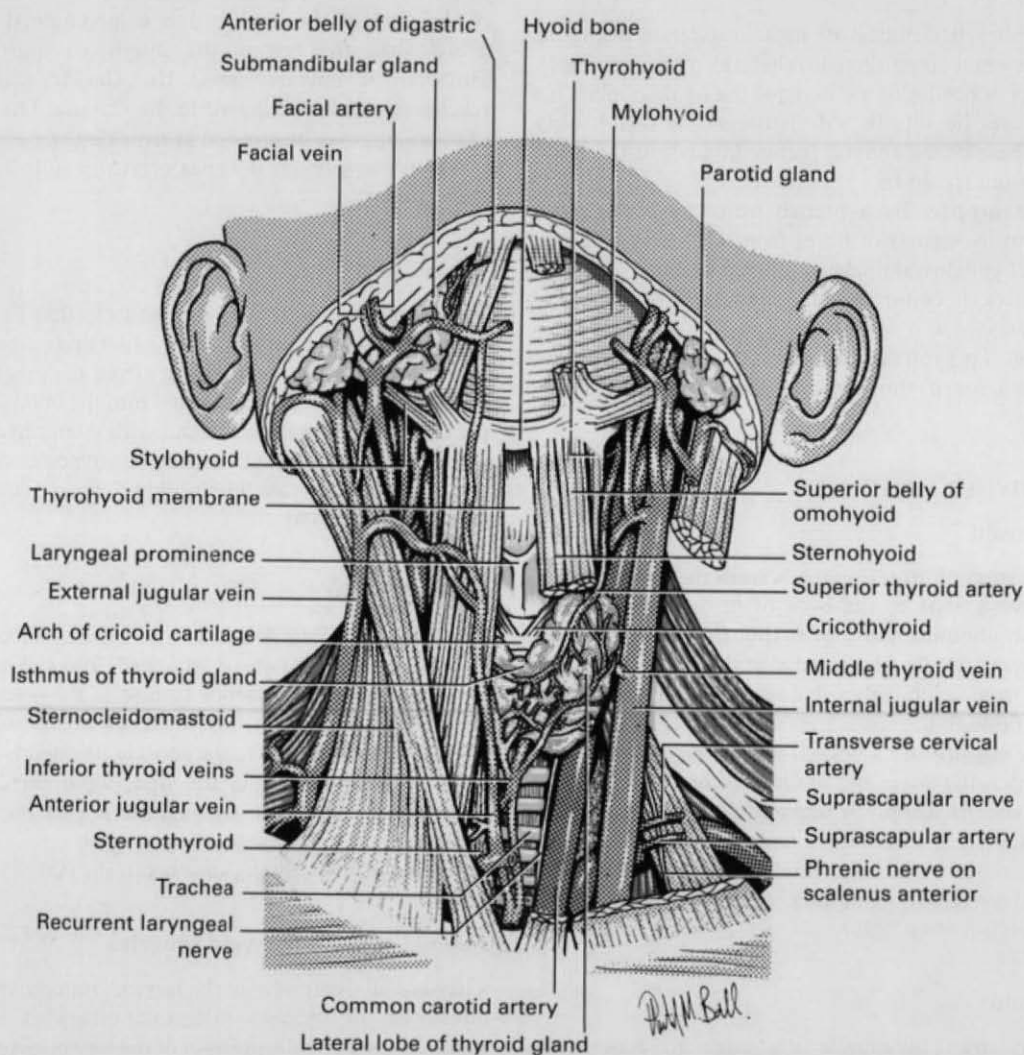


Fig. 6.4 Thyroid gland and the front of the neck.

THYROID GLAND

The **thyroid gland** consists of two symmetrical lobes united in front of the second, third and fourth tracheal rings by an isthmus of gland tissue (Fig. 6.4). Apart from its own thin capsule it is enclosed by an envelope of pretracheal fascia.

Each **lateral lobe** is pear-shaped with a narrow upper pole and a broader lower pole, and appears approximately triangular on cross-section with lateral, medial and posterior surfaces.

The **lateral (superficial) surface** is under cover of sternothyroid and sternohyoid; the upper pole is tucked

away beneath the upper end of sternothyroid which limits extension of an enlarging lobe. The lower end of sternocleidomastoid overlaps these strap muscles.

The **medial surface** lies against the lateral side of the larynx and upper trachea, the lower pole extending along the side of the trachea as low as the sixth tracheal ring, with the lower pharynx and upper oesophagus immediately behind. The cricothyroid muscles of the larynx and the inferior constrictor of the pharynx are medial muscular relations of this surface, with the external and recurrent laryngeal nerves approaching it from above and below respectively (see below).

The **posterior surface** overlaps the medial part of the

carotid sheath, i.e. the part containing the common carotid artery; if enlarged, the lobe may extend across the more laterally placed internal jugular vein. The parathyroid glands usually lie in contact with this surface, between it and the fascial sheath. The inferior thyroid artery arches behind the lower pole (at the level of C6 vertebra), and on the left the thoracic duct also describes a similar arch but at a lower level (C7 vertebra).

Of all the structures related to the thyroid lobes, the **recurrent laryngeal nerve** (p. 464) must take pride of place in view of its importance in thyroid surgery. Approaching the medial surface of the gland from below, and at this level usually *in front of* the groove between the trachea and oesophagus, the left nerve is more likely to lie behind the inferior thyroid artery than in front of it (see below), while on the right there is an equal chance of it lying in front of or behind the artery; but either may pass between branches of the artery. A minute artery is usually visible on the surface of the nerve and helps to identify it. The nerve is always *behind the pretracheal fascia* (including the thickening of it attached to the cricoid cartilage and sometimes called the *suspensory ligament of Berry*), and *behind the cricothyroid joint*, whence it passes upwards under cover of the inferior constrictor. At the level of the upper border of the isthmus the nerve often divides into two. If so, the anterior (larger) branch is the motor branch to laryngeal muscles, and the posterior branch is sensory only. The occasional non-recurrent right laryngeal nerve must be remembered (p. 41).

The *external laryngeal nerve*, smaller and much less important than the recurrent laryngeal, runs down to supply cricothyroid and in its course lies a millimetre or two behind the superior thyroid artery, passing medial to the upper pole.

The **isthmus** joins the anterior surfaces of the lobes, towards their lower poles. The posterior surface of the isthmus is firmly adherent to the second, third and fourth rings of the trachea, and the pretracheal fascia is here fixed between them. This fixation and the investment of the whole gland by pretracheal fascia are responsible for the gland moving up and down with the larynx during swallowing.

An anastomosis between the two superior thyroid arteries runs across the upper border of the isthmus, and tributaries of the inferior thyroid veins emerge from its lower border. A small portion of gland substance often projects upwards from the isthmus, generally to the left of the midline, as the **pyramidal lobe** and represents a development of glandular tissue from the caudal end of the thyroglossal duct (p. 39). It is attached to the inferior border of the hyoid bone by fibrous

tissue; muscle fibres sometimes present in it are named *levator glandulae thyroideae* and are innervated by a branch of the external laryngeal nerve.

Separate masses of thyroid tissue (*accessory thyroid glands*) are not uncommonly found near the hyoid bone, in the tongue, in the superior mediastinum, or beneath the sternocleidomastoid muscle.

Blood supply

The **superior thyroid artery**, the first branch from the anterior aspect of the external carotid (p. 437), after giving off its sternocleidomastoid and superior laryngeal branches, pierces the pretracheal fascia as a single vessel to reach the summit of the upper pole. The external laryngeal nerve is immediately behind the artery as the vessel approaches the pole; in thyroidectomies the artery is ligated right at the pole, not some distance from it, to avoid damage to the nerve. The artery divides on the gland into an *anterior branch* that runs down to the isthmus and a *posterior branch* that runs down the back of the lobe and anastomoses with an ascending branch of the inferior thyroid artery from the lower pole. A separate branch from the left artery may supply the pyramidal lobe.

The **inferior thyroid artery**, from the thyrocervical trunk (p. 444), arches upwards and medially behind the lower pole and divides *outside* the pretracheal fascia into four or five branches that pierce the fascia separately to reach the lower pole of the gland. The suspensory ligament always contains small branches. The recurrent laryngeal nerve has a variable relationship to the artery (see above) but always lies behind the pretracheal fascia, and if this structure remains intact during thyroidectomy the nerve will not have been divided. It is close behind the fascia, however, and may be bruised or caught in a ligature; hence the preference of some, but not all, surgeons of ligating the inferior thyroid artery well lateral to the gland before it begins to divide into its terminal branches. (Note that the inferior thyroid artery gives off oesophageal and inferior laryngeal branches before its terminal distribution into the thyroid gland.)

The **thyroidea ima artery** enters the lower part of the isthmus in 3% of individuals. It springs from the brachiocephalic trunk, right common carotid artery or direct from the arch of the aorta, and represents a persistent embryonic vessel that usually disappears.

The *venous return* from the upper pole follows the superior thyroid artery. The **superior thyroid vein** enters either the internal jugular or facial vein in about equal proportions. The **middle thyroid vein**, short and wide, is usually present. It passes from the middle

of the lobe, directly into the internal jugular vein. From the isthmus and lower poles the **inferior thyroid veins** form a plexus that lies in the pretracheal fascia, in front of the cervical part of the trachea. The plexus drains into the brachiocephalic veins, most of it into the left one.

Lymph drainage

The lymphatics follow the arteries. From the upper pole they enter the anterosuperior group of deep cervical lymph nodes. From the lower pole they pass with the inferior thyroid artery back to its point of origin from the subclavian behind the carotid sheath into the posteroinferior group. A few pass downwards into pretracheal nodes, following the course of the thyroidea ima artery.

Nerve supply

The bulk of the sympathetic (vasoconstrictor) supply is derived from the middle cervical ganglion and enters the gland on the inferior thyroid artery; some fibres from the superior cervical ganglion travel with the superior thyroid artery. Vagus nerve filaments are traceable to the gland; their purpose is unknown.

Structure

The thyroid consists essentially of a mass of more or less rounded *follicles* (sometimes called vesicles) full of *colloid*, the iodine-containing product of the single layer of *epithelial (follicular) cells* that form the walls of the follicles. The thyroid is thus unique in being the only endocrine gland to store its secretion outside the cells. The colloid is iodinated when in the follicle, not in the cells, and reabsorbed by the cells before being discharged into blood capillaries. Most histological sections give little idea of the great vascularity of the gland, which, in proportion to its size, has one of the highest bloodflows of any organ. The main hormonal products are thyroxine (T_4) and triiodothyronine (T_3). Less than 2% of the epithelial cells are the C or *parafollicular cells* which secrete calcitonin. Difficult to see histologically, they are easy to identify with the electron microscope because of their content of secretory granules. The C cells are scattered on the outer aspects of the follicles and do not reach the lumina of the follicles.

Development

The gland develops as a proliferation of cells from the caudal end of the thyroglossal duct (p. 39). The para-

follicular calcitonin-producing cells are now known to come from the ultimobranchial body (fifth pharyngeal pouch), but no other part of the gland is derived from pharyngeal pouches.

Surgical approach

For *partial thyroidectomy* through a transverse skin incision 2.5 cm above the jugular notch, the gap between the sternohyoids and sternothyroids is opened up to expose the trachea and the isthmus, and the muscles are retracted laterally, or if necessary divided near their upper ends (so preserving their nerve supplies from the ansa cervicalis) to display the lateral lobes. The vessels of each lobe are ligated and divided, and the required portion of each lobe removed (leaving the parathyroids intact). The position of the recurrent laryngeal nerves has been emphasized above. Enlarged lobes may stretch the strap muscles and it is important to define properly the plane deep to sternothyroid and sternohyoid, and not to damage the thin-walled internal jugular vein.

PARATHYROID GLANDS

The parathyroid glands normally lie behind the lateral lobe of the thyroid gland, and may be either within or outside the thyroid's capsule of pretracheal fascia. There are usually four glands (in 90% of subjects), two on each side, with a total weight of not more than 200 mg.

The *superior gland* is the more constant in position; it is usually on the back of the thyroid lobe, level with the first tracheal ring and above the inferior thyroid artery. The *inferior gland* is the more variable in position (see Development, below), usually behind the lower pole, below the inferior thyroid artery and lateral to the recurrent laryngeal nerve. The glands are not necessarily on the same level on each side. They are brownish-yellow in colour, which should help to distinguish them from thyroid tissue and fat. They are sometimes (especially the inferior gland) embedded within the thyroid lobe rather than being behind it. If they are difficult to find, follow the branches of the inferior thyroid artery upwards and downwards; a small branch enters each gland — a further distinguishing feature from a globule of fat.

Blood supply

Both upper and lower parathyroids are usually supplied by the inferior thyroid artery, with minute veins joining thyroid vessels.

Lymph drainage

As for the thyroid gland (above) and thymus (p. 263).

Nerve supply

Sympathetic vasoconstrictor fibres enter with the arteries.

Structure

In histological section the gland is homogeneous and very vascular, two points that aid identification. The gland is a mass of small closely-packed chief or *principal cells* which secrete the parathyroid hormone (PTH). The mass of cells bears a superficial resemblance to lymphoid tissue, but the number of blood capillaries in the gland provides a clear distinction. Scattered among the chief cells are small groups of slightly larger *oxyphil cells*, probably derived from the chief cells but of unknown function.

Development

The superior gland is often called *parathyroid IV* because it develops from the dorsal diverticulum of the fourth pharyngeal pouch; the inferior gland is *parathyroid III*, developed from the third pouch but displaced caudally by the descent of the thymus from the same pouch (p. 39). Thus the inferior gland, developed higher up, has farther to migrate than the superior and is more liable to end up in unusual positions. About 10% of inferior glands are found within the capsule of the thymus, and other aberrant glands may be found in the lower neck or the posterior or anterior mediastinum.

Surgical approach

For *parathyroidectomy* the lobes of the thyroid gland are exposed as for thyroidectomy, and then retracted forwards and medially so that the posterior surfaces can be inspected for the parathyroids. If not obvious, branches of the inferior thyroid artery are followed and should lead to the glands. Exposure of the thymus may be necessary. If all four glands are to be removed, part of one of them is implanted into the brachioradialis muscle of an arm, where it should act as an endocrine graft; if later surgery on it is required (for recurrent hyperparathyroidism) it is easier to approach an arm than the neck.

TRACHEA

The **trachea** (Fig. 6.4) which begins at the level of C6

vertebra is in continuity with the larynx, being attached to the lower margin of the cricoid cartilage by the cricotracheal ligament. Its patency as an airway is maintained by the presence in its wall of a series of C-shaped hyaline cartilages (commonly called rings although they are never complete circles) joined together by a fibroelastic membrane. The gaps in the C-shaped rings lie posteriorly and this part of the trachea is closed by a sheet of visceral muscle, the *trachealis*. From the neck the trachea passes into the thorax, and so has cervical and thoracic parts. Of the total length of 10 cm (4 in), 5 cm are in the neck from the cricoid cartilage to the jugular notch, but during deep inspiration the total length may increase to 15 cm.

The *cervical part* lies in the midline of the neck, in contact with the front of the oesophagus. In the groove between trachea and oesophagus runs the recurrent laryngeal nerve. To the side of the trachea is the carotid sheath. The isthmus of the thyroid gland is adherent to the second, third and fourth tracheal rings and the lobes of the gland lie against the lateral side of the trachea as far down as the sixth ring. The inferior thyroid veins and anterior jugular venous arch lie in front, and also (if present) the thyroidea ima artery, the levator glandulae thyroideae and the upper end of a persistently large thymus. It is important to appreciate that, because of the shape of the lower cervical and upper thoracic parts of the vertebral column, the trachea passes not only downwards but *backwards* as well. Although just below the skin at cricoid level, it is 2 cm or more deep to the front of the jugular notch.

The *thoracic part* of the trachea and other features are described on page 260.

Tracheotomy and tracheostomy

Tracheotomy implies making an incision in the trachea; tracheostomy involves removing a small part of the wall (making a stoma), but the strict distinction between these terms is often ignored. As an emergency procedure tracheotomy is nowadays usually replaced by laryngotomy (incising the cricothyroid ligament — p. 498). For *elective tracheostomy*, a transverse skin incision is made 2 cm below the cricoid cartilage. The interval between the two sternohyoid muscles is opened up and the slightly deeper sternothyroids are retracted laterally. The isthmus of the thyroid gland is divided and an opening made by removing part of the second and third tracheal rings so that a tracheostomy tube can be inserted. Haemorrhage from the isthmus and inferior thyroid veins should be easily avoided in an elective procedure.

OESOPHAGUS

The **oesophagus** commences in continuity with the cricopharyngeus muscle at the level of the lower border of the cricoid cartilage (C6 vertebra). Its inner muscular coat breaks free from the lower border of this muscle to form a continuous circular coat. The outer longitudinal coat is attached to the midline ridge of the lamina of the cricoid cartilage and to the arytenoid cartilages. The fibres spiral down from this origin to the back of the oesophagus, whence the longitudinal coat is continuous (Fig. 6.30).

The cervical part of the oesophagus lies in front of C6 and 7 vertebrae and the prevertebral fascia and behind the trachea. It is overlapped by the lower poles of the thyroid gland, and the thoracic duct runs upwards behind its left border. The recurrent laryngeal nerves are on each side in the groove between trachea and oesophagus.

The rest of the oesophagus is described on page 277.

Carotid sheath

The upper part is described on page 462. The lower part contains the common carotid artery, internal jugular vein, vagus nerve and the ansa cervicalis.

It is free posteriorly to slide over the prevertebral fascia, but is connected anteriorly by fibrous tissue to the fascia on the deep surface of sternocleidomastoid. Pus tracking laterally from around the pharynx thus passes behind, not in front of the sheath, to point in the posterior triangle. The sheath is very thin over the internal jugular vein, which is thus free to dilate enormously for increased bloodflow. The 'dead space' around the vein contains the inferior deep cervical lymph nodes in anterior and posterior groups, the latter extending behind sternocleidomastoid into the posterior triangle, forming a supraclavicular group (p. 426).

The *lower part* of the carotid sheath extends from the sternoclavicular joint vertically upwards to the level where the common carotid artery bifurcates into the external and internal carotids. This level is usually stated to be at the upper border of the thyroid cartilage (upper part of C4 vertebra), but is frequently higher, near the tip of the greater horn of the hyoid bone (C3 vertebra). The terminal portion of the artery is often dilated into the carotid sinus, continuous with that on the commencement of the internal carotid artery (p. 438).

The **common carotid artery** arises on the *left* side from the arch of the aorta, where it lies in front of the subclavian artery up to the sternoclavicular joint. Here the two arteries diverge. On the *right* the brachio-

cephalic trunk bifurcates behind the sternoclavicular joint into common carotid and subclavian arteries. The common carotid gives off no branches proximal to its bifurcation. It lies within the medial part of the carotid sheath, lateral to the larynx and trachea, with the internal jugular vein lateral to it and the vagus nerve deeply placed between the two vessels. The sympathetic trunk is behind the artery and outside the sheath, which is overlapped superficially by the infrahyoid muscles and sternocleidomastoid.

The *carotid pulse* can be felt by pressing backwards between the trachea and lower larynx medially and sternocleidomastoid laterally, i.e. pressing the artery against the tubercle of the transverse process of C6 vertebra. The *surface marking* of the common carotid artery is along a line from the sternoclavicular joint to the bifurcation near the greater horn of the hyoid bone. The vessel can be surgically *exposed* by retracting the lower part of sternocleidomastoid backwards and incising the carotid sheath.

The *internal jugular vein* and *vagus nerve* are described on pages 438 and 464.

The **ansa cervicalis** lies on the front of the internal jugular vein and gives branches to the infrahyoid muscles. It is *embedded within* the anterior wall of the carotid sheath and classified as one of its contents. It is formed by union of superior and inferior roots. The *superior root* (descendens hypoglossi) is a branch of the hypoglossal nerve (see below) given off where the nerve loops just below the posterior belly of digastric, on the occipital, external carotid and lingual arteries. It runs down on the front of the internal jugular vein, and contains only C1 fibres, which have hitch-hiked along the hypoglossal nerve.

The *inferior root* (descendens cervicalis) is formed by union of a branch each from C2 and C3 anterior rami in the cervical plexus. The single nerve so formed spirals from behind around the internal jugular vein and runs down to join the superior root at a variable level. Sometimes a wide loop is formed over the lower part of the vein and the branches arise from the loop. Sometimes the two nerves join, Y-shaped, high up and the branches are given off from the stem of the Y. In either case they are distributed to the infrahyoid muscles (sternohyoid, sternothyroid and omohyoid) segmentally, C1, C2 and C3 from above down.

The upper part of the **hypoglossal nerve** is described on page 465. In the submandibular region it emerges between the internal carotid artery and internal jugular vein deep to the posterior belly of digastric. Hooking round the occipital artery it curves forwards over the external carotid and the loop of the lingual artery (Fig. 6.17). As it crosses these three

arteries it lies just below digastric, behind its tendon and just above the tip of the greater horn of the hyoid bone; this is where to look for it in dissections. Here it gives off the superior root of the ansa cervicalis. It passes forwards on the surface of hyoglossus which separates it from the lingual artery, giving off the branch to thyrohyoid (C1 fibres) and then running deep to mylohyoid to enter the mouth (p. 484).

PART 3

SUPRAHYOID REGION

The hyoid bone is connected to the mandible by a thin sheet of muscle, the mylohyoids (p. 428), which form the floor of the mouth. Superficially (i.e. below it) lies the anterior belly of digastric. The nerve to mylohyoid and the submental branch of the facial artery run between the two, while lying upon it, half hidden under the mandible, are the submandibular salivary gland and lymph nodes. These structures are covered in by the investing layer of deep cervical fascia, which is attached to the hyoid bone and the inferior border of the mandible. In the subcutaneous tissue lie the platysma muscle, the anterior jugular veins and the submental lymph nodes. The skin of this region is supplied by the upper division of the transverse cervical nerve (C2).

Platysma

This part of the panniculus carnosus forms a broad flat sheet that extends from the deep fascia over the upper part of pectoralis major and the most anterior part of deltoid to the lower border of the mandible, with some fibres reaching the lateral part of the lower lip by passing beneath depressor anguli oris. The muscle covers the external and anterior jugular veins. The two muscles are separated below, but converge above towards the midline and overlap just beneath the chin. The lateral border of each muscle slants up across the parotid gland and converges into a triangle whose apex is attached to the modiolus, constituting the *risorius muscle*.

Nerve supply. By the cervical branch of the facial nerve, but afferent (proprioceptive) fibres run with the transverse cervical nerve.

Action. It plays a part in facial expression and may assist in opening the mouth. In 'forcibly showing the teeth' (p. 641) and in strenuous activity it raises longitudinal ridges of cervical skin, and possibly helps to relieve pressure on cervical veins. In facelift operations

it can be attached to sternocleidomastoid high up behind the ear; skin is mobilized superficial to the muscle to avoid damage to its nerve supply.

Anterior jugular veins

These commence beneath the chin and pass downwards, side by side beneath the platysma, to the suprasternal region (Fig. 6.4). Here they pierce the deep fascia and come to lie in the suprasternal space, where they are often connected by a short anastomotic vein. Each now angles laterally and passes deep to sternocleidomastoid to open into the external jugular vein after the latter has pierced the deep fascia.

Submental and submandibular lymph nodes

Three or four small **submental nodes** lie beneath the chin, some superficial and others deep to the investing layer of deep cervical fascia. They drain, across the midline, a wedge of tissue in the floor of the mouth opposite the four lower incisor teeth, including those teeth, gums and lip, and the tip of the tongue (see p. 482). In their turn they drain to submandibular nodes or directly to the upper deep cervical group (Fig. 6.57).

Half a dozen **submandibular lymph nodes** lie on the surface of the submandibular gland, though some may be embedded within the gland. They drain the submental nodes, the lateral parts of the lower lips, all the upper lip and external nose, and the anterior part of the tongue, mainly but not exclusively from their own side. They also receive from the anterior half of the nasal walls and the paranasal sinuses that drain there (frontal, anterior and middle ethmoidal, and maxillary), and all teeth (except lower incisors).

Submandibular fossa

This space lies deep to the investing layer of deep cervical fascia and the inferior border of the mandible. The fascia is attached to the inferior border of the mandible and to the whole length of the hyoid bone up to the tip of the greater horn. It is a demonstrable membrane that spans the fossa and supports the submandibular gland, giving only a very tenuous capsule round the deep surface of the gland (nothing like as thick as that of the parotid gland). Deep to this the fossa extends to the mylohyoid muscle (Fig. 6.5); the space thus projects upwards under cover of the mandible as high as the mylohyoid line. Swelling in the space is limited by the attachments of the mylohyoid muscle and the deep fascia; distension of the space is

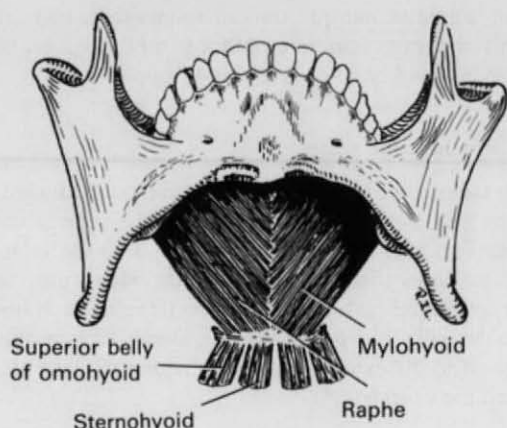


Fig. 6.5 Mylohyoid muscles from below and in front.

seen in Ludwig's angina (a cellulitis usually due to infection spreading from teeth or tonsil).

The *nerve to mylohyoid* branches from the inferior alveolar nerve at the mandibular foramen (p. 461) and pierces the sphenomandibular ligament at its attachment to the inferior margin of the foramen. It is accompanied by small branches of the inferior alveolar artery and vein; the vessels indent the mandible, forming the mylohyoid groove. The groove marks the upper limit of the attachment of the medial pterygoid muscle (Fig. 8.14, p. 664). The small artery supplies the periosteum and some fibres of the medial pterygoid; the nerve, however, passes forwards on the neck surface of the mylohyoid muscle. It ends between the anterior belly of digastric and mylohyoid, supplying both. It is accompanied by the *submental branch of the facial artery*, which gives off a branch that perforates the mylohyoid to supply the anterior part of the floor of the mouth, including the sublingual gland. *Submental veins* run back to the facial vein. Lymphatics pierce the anterior part of mylohyoid to drain tip of tongue and floor of mouth into the submental lymph nodes (Fig. 6.24, p. 482).

SUBMANDIBULAR GLAND

The **submandibular gland**, mixed mucous and serous in man, consists of a large superficial part and a small deep part which are continuous with one another round the free posterior margin of mylohyoid (Fig. 6.17).

The *superficial part* fills some of the space between the mandible, mylohyoid and the investing layer of deep cervical fascia, and so has three surfaces which may be called lateral, inferior and medial. The *lateral surface* lies against the submandibular fossa of the mandible

(p. 664), overlapping the front of the medial pterygoid insertion and being deeply grooved posteriorly by the facial artery which hooks under the mandible to reach the face at the front of the masseter muscle. The *inferior* or *superficial surface* is covered by skin, platysma and the investing fascia and is crossed by the facial vein and the cervical branch of the facial nerve, and also by the marginal mandibular branch of the facial nerve if unusually low (p. 450). Submandibular lymph nodes lie not only in contact with the surface of the gland but also within its substance — hence the need to remove the gland as well as nodes in the operation of radical neck dissection. Most of the *medial surface* lies against mylohyoid and its vessels, but towards the back it overlaps hyoglossus and the lingual nerve, submandibular ganglion, hypoglossal nerve and deep lingual vein.

The *deep part* of the gland extends forwards for a variable distance, sometimes only a few millimetres, between mylohyoid and hyoglossus, with the lingual nerve above it and the submandibular duct and hypoglossal nerve below it.

The **submandibular duct** (of Wharton) is 5 cm long (the same length as the parotid duct) and emerges from the superficial part of the gland near the posterior border of mylohyoid. It runs forwards first between mylohyoid and hyoglossus and then between the sublingual gland and geniohyoid, to open into the floor of the mouth beside the frenulum (p. 484).

Blood supply

From the facial artery, with veins draining into the facial vein.

Lymph drainage

To the submandibular lymph nodes.

Nerve supply

Secretomotor fibres to the gland have their cell bodies in the submandibular ganglion (pp. 34 and 485) with a few in small ganglionic masses on the surface of the gland itself. The preganglionic fibres pass from cell bodies in the superior salivary nucleus in the pons by way of the nervus intermedius, chorda tympani and the lingual nerve (p. 461). Sympathetic (vasoconstrictor) fibres come from the plexus around the facial artery.

Structure

See the section on the parotid gland for comparison of salivary gland structure.

Development

A groove in the floor of the mouth becomes converted into a tunnel whose blind end proliferates to form the secreting acini. Its origin is almost certainly ectodermal (p. 37).

Surgical approach

The superficial part is easy to expose under platysma, but the skin incision must be made about 4 cm below the mandible to avoid the marginal mandibular branch of the facial nerve which may lie over the gland (p. 450). Removal of the gland requires ligation of the facial artery and vein above and below it, and the gland is dissected away from the lingual nerve, with ligation of the duct as it lies on hyoglossus. The removal of a stone from the duct is carried out from within the mouth by incising the duct over the stone; the duct does not need to be sutured.

GREAT VESSELS OF THE NECK

The principal vessels of the neck are the common, external and internal carotid arteries and the internal jugular vein. The course of the common carotid artery within the carotid sheath has already been noted (p. 434).

External carotid artery

The **external carotid artery** commences at the bifurcation of the common carotid (p. 434), near the greater horn of the hyoid bone. At first somewhat medial to, it slopes upwards in front of, the internal carotid artery and passes deep to the posterior belly of digastric and stylohyoid, above which it pierces the deep lamina of the parotid fascia and enters the gland. It divides when within the gland behind the neck of the mandible into maxillary and superficial temporal arteries.

At its commencement the external carotid lies against the side wall of the pharynx; its place is soon taken by the internal carotid artery, which then lies against the pharynx all the way up to the base of the skull. As the external carotid artery lies in the parotid gland it is separated from the internal carotid by the deep part of the gland and the 'pharyngeal' structures: stylopharyngeus muscle, glossopharyngeal nerve and pharyngeal branch of the vagus (and, if present, the track of a branchial fistula). At the commencement of the artery the internal jugular vein lies lateral, but higher up it is posterior and deep to the artery. The facial vein crosses the artery, with the hypoglossal nerve lying between.

Except at its commencement the vessel lies in front of the anterior border of sternocleidomastoid.

The *surface marking* of the external carotid is along a line from the bifurcation of the common carotid near the greater horn of the hyoid, passing behind the angle of the mandible to a point immediately in front of the tragus of the ear.

Surgical approach. The vessel can be exposed in front of the upper part of sternocleidomastoid before entering the parotid gland by ligating the facial vein and incising the carotid sheath. The hypoglossal nerve which crosses the external and internal carotids superficially must not be damaged.

Branches. Before it enters the parotid gland the external carotid artery gives off *six branches*, three from in front, two from behind and one deep (medial). The three from in front are the superior thyroid, lingual and facial, and they diverge widely. The two from behind are the occipital and posterior auricular, which pass up along the lower and upper borders of the posterior belly of digastric. The branch from the medial side is the ascending pharyngeal, which ascends to the base of the skull on the side wall of the pharynx, alongside the internal carotid artery.

The **superior thyroid artery** arises at the commencement of the external carotid. It slopes almost vertically downwards, with the vein, to the upper pole of the thyroid gland (p. 431). Close behind it, alongside the larynx, lies the external laryngeal nerve (Fig. 6.17). The main branch is the *superior laryngeal artery* which pierces the thyrohyoid membrane with the internal laryngeal nerve. It also gives a branch to sternocleidomastoid.

The **lingual artery** arises from the front of the external carotid above the superior thyroid. It forms a short upward loop (Fig. 6.17), then passes forwards along the upper border of the greater horn of the hyoid bone, deep to hyoglossus (p. 482). It is accompanied by the deep lingual vein which passes back to the sublingual vein. It is crossed by the hypoglossal nerve and its companion vein, the latter opening into the facial vein. The facial vein overlies the hypoglossal nerve and the loop of the lingual artery on its way to the internal jugular.

The **facial artery** arises from the front of the external carotid above the lingual artery (sometimes by a common *linguofacial trunk* with the lingual) and runs upwards on the superior constrictor, deep to the digastric and stylohyoid muscles, then deep to the submandibular salivary gland. It indents the surface of the gland. As the artery lies on the superior constrictor muscle it gives off a *tonsillar branch* to the tonsil and soft palate. The facial artery then makes an S-bend, curling

down over the submandibular gland (Fig. 6.25) and up over the mandible, whose periosteum it supplies. Just before it crosses the inferior border of the mandible, where its pulsation can be felt 2.5 cm in front of the angle at the anterior border of masseter, it gives off a sizable branch, the **submental artery**, which accompanies the mylohyoid nerve into the submandibular fossa. There it supplies the anterior belly of digastric and mylohyoid, and sends perforating branches through the floor of the mouth to the sublingual gland.

The **occipital artery** arises from the back of the external carotid on a level with the facial artery. It courses along the lower border of the posterior belly of digastric, passing deeper and grooving the base of the skull at the occipitomastoid suture deep to the digastric notch on the mastoid process. It passes back through the apex of the posterior triangle to supply the back of the scalp (p. 453). The artery gives off two branches to sternocleidomastoid. The upper branch is a guide to the accessory nerve in front of the upper border of the muscle. The artery at its origin is crossed by the hypoglossal nerve, which hooks around it from behind; here the nerve is held down by the lower sternocleidomastoid branch of the artery (Fig. 6.17)

The **posterior auricular artery** arises above the level of the digastric muscle, sometimes within the substance of the parotid gland. It runs up superficial to the styloid process across the upper border of digastric, and crosses the surface of the mastoid process. It supplies the skin over the mastoid process; it is cut in incisions for mastoid operations. Auricular branches supply the pinna of the ear. Its *stylomastoid branch* enters the stylomastoid foramen, supplies the facial nerve and gives off the *stapedial artery* to the stapedius muscle, of interest as being the remnant of the artery of the second pharyngeal arch (p. 40).

The **ascending pharyngeal artery** arises just above the commencement of the external carotid, from its deep aspect. It runs up along the side wall of the pharynx in front of the prevertebral fascia, deep to the internal carotid artery. It supplies the pharyngeal wall and the soft palate and sends meningeal branches through the foramina nearby (foramen lacerum, jugular foramen, hypoglossal canal).

Internal carotid artery

The **internal carotid artery** arises at the bifurcation of the common carotid (p. 434) and continues upwards within the carotid sheath (p. 462). At its commencement it shows a slight bulge, the **carotid sinus**. Here the arterial wall is thin and its contained *baroreceptors* are supplied by the carotid sinus branch of the glosso-

pharyngeal nerve which mediates blood pressure impulses to medullary centres. The **carotid body** is a small yellowish-grey structure lying behind the bifurcation of the common carotid artery, from which it receives two or three very small glomic arteries. Its cells are *chemoreceptors* concerned (like the aortic bodies—p. 256) with respiratory reflexes, and in proportion to its size it has the highest bloodflow of any organ in the body. Its glomus cells, which have vesicles containing dopamine, are innervated by the glossopharyngeal nerve. Carotid body tumours form a swelling at the anterior border of sternocleidomastoid at the level of the carotid bifurcation, and exhibit transmitted pulsation from the arteries.

The internal carotid artery is really external (lateral) to the external carotid at its origin, but soon slopes up posteriorly to occupy a medial and deeper level. It has no branches and passes straight up in the carotid sheath and beside the pharynx to the carotid canal in the base of the skull, wherein its further course is considered on page 570.

Behind the internal carotid artery in the neck is the sympathetic trunk (outside the carotid sheath), and the pharyngeal veins usually pass behind to reach the internal jugular vein. The superior laryngeal branch of the vagus crosses obliquely behind to reach its medial side where it divides into the internal and external laryngeal nerves. The ascending pharyngeal artery is also medial to it. The internal jugular vein is lateral, with the vagus nerve deeply placed between artery and vein. Superficially near its origin it is crossed by the lingual and facial veins, the occipital artery and hypoglossal nerve; the superior root of the ansa cervicalis runs downwards along it, embedded in the carotid sheath. At a higher level it is overlapped by sternocleidomastoid and crossed by the posterior belly of digastric and stylohyoid and the posterior auricular artery, and by the structures that separate it from the external carotid, namely stylopharyngeus, the glossopharyngeal nerve and the pharyngeal branch of the vagus (and if present the track of a branchial fistula).

The *surface marking* of the internal carotid artery in the neck is along a line from the bifurcation of the common carotid artery near the greater horn of the hyoid bone to the head of the mandible.

Surgical approach. The internal carotid is exposed by retracting the upper part of sternocleidomastoid backwards, ligating the facial vein and incising the carotid sheath.

Internal jugular vein

The **internal jugular vein** emerges from the jugular

bulb at the posterior compartment of the jugular foramen. At first behind the internal carotid artery, it lies on the lateral mass of the atlas, crossed by the accessory nerve. It receives the inferior petrosal sinus as its first tributary, just below the base of the skull; the sinus passes back lateral (or sometimes medial) to the vagus nerve. The vein passes down to gain the lateral side of the internal carotid artery within the loose lateral part of the carotid sheath, with the vagus nerve deeply placed between the vein and arteries. In the lower part of their course the vessels are overlaid by the sloping sternocleidomastoid. Deep cervical lymph nodes are closely adjacent to the vein throughout its course. Its posterior relations include the cervical plexus lying on levator scapulae and scalenus medius, and the phrenic nerve on scalenus anterior. The thoracic duct crosses behind the left vein at the level of C7 vertebra. The inferior root of the ansa cervicalis curls round its lateral border, to unite with the superior root (from the hypoglossal nerve) at a variable level in front of the vein. Low down the tendon of omohyoid crosses the vein, providing a useful guide to its position. The termination of the vein lies beneath the triangular interval between the sternal and clavicular head of sternocleidomastoid, where it joins the subclavian to form the brachiocephalic vein.

The tributaries of the internal jugular vein below the inferior petrosal sinus are, in order from above downwards, the pharyngeal plexus, facial, lingual, and superior and middle thyroid veins. The facial, lingual and superior thyroid veins usually join it near the tip of the greater horn of the hyoid, but as with most veins there are many variations in the way they may join with another or with the main vein.

The *surface marking* of the internal jugular vein is along a line from the lobule of the ear to the sternal end of the clavicle. The jugular venous pulse is a guide to jugular venous pressure, which is the same as right atrial or central venous pressure and thus an important indicator of cardiovascular function. With a patient reclining at 45° the jugular venous pulse should be visible just above the clavicle.

Catheterization. The right internal jugular vein (on a direct path to the right atrium) can be cannulated for the insertion of a central venous line, for measurements of central venous pressure or the rapid administration of drugs when a peripheral approach would be too slow. The vein is usually approached from a point 5 cm above the clavicle at the posterior border of sternocleidomastoid, and the needle is directed towards the jugular notch, entering the vein in about 4–5 cm. It can also be entered from 2 cm above the clavicle between the two heads of sternocleidomastoid in a backward and slightly

lateral direction. (The subclavian vein is an alternative — p. 442.) The commonest complication is haematoma formation and perhaps puncture of the more medially situated common carotid artery.

SUMMARY OF TRIANGLES OF THE NECK

Now that the regions of the anterior and posterior triangles have been studied, it is convenient to record in summary form the principal features, not simply as mere lists for recital parrot-fashion but as an aid to recalling where to locate them, always remembering that some important structures such as the internal jugular vein, common carotid artery and vagus nerve are under cover of the undisturbed sternocleidomastoid and so do not appear in these triangles.

Posterior triangle

Boundaries. Sternocleidomastoid, trapezius, clavicle.

Contents. Occipital, transverse cervical, suprascapular and subclavian arteries; transverse cervical, suprascapular and external jugular veins; cervical plexus branches and brachial plexus trunks; omohyoid; lymph nodes.

Anterior triangle

Boundaries. Sternocleidomastoid, mandible, midline. Subdivided into:

Carotid triangle

Boundaries. Sternocleidomastoid, posterior belly of digastric, superior belly of omohyoid.

Contents. Bifurcation of common carotid artery and branches of external carotid (except posterior auricular); hypoglossal, internal and external laryngeal nerves; lymph nodes.

Digastric triangle

Boundaries. Mandible, anterior and posterior bellies of digastric.

Contents. Submandibular gland and lymph nodes; facial, submental and mylohyoid vessels; hypoglossal and mylohyoid nerves.

Submental triangle

Boundaries. Anterior belly of digastric, body of hyoid bone, midline.

Contents. Anterior jugular vein; lymph nodes.

Muscular triangle

Boundaries. Sternocleidomastoid, superior belly of omohyoid, midline from hyoid bone to jugular notch.

Contents. Part of larynx and thyroid gland; lymph nodes.

PART 4

PREVERTEBRAL REGION

PREVERTEBRAL MUSCLES OF THE NECK

Some relatively weak flexor muscles extend in front of the vertebral column from skull to superior mediastinum. They are covered anteriorly by the strong prevertebral fascia (Fig. 6.6), upon whose slippery surface the pharynx and oesophagus glide freely during neck movements or swallowing.

Rectus capitis anterior extends from the lateral mass of the atlas to the front of the foramen magnum.

Rectus capitis lateralis lies edge to edge with the former muscle; it extends from the lateral mass of the atlas to the jugular process of the occipital bone. The **anterior ramus of C1**, passing forwards lateral to the atlanto-occipital joint, supplies each muscle and then passes between them to sink into the overlying longus capitis muscle. It gives a branch to the hypoglossal nerve, which is distributed in the meningeal branch, the superior root of the ansa cervicalis and the branches to thyrohyoid and geniohyoid. These two small rectus muscles assist in flexion and lateral flexion of the head.

Longus capitis is attached by four slender tendons, in line with those of scalenus anterior, to the anterior tubercles of the four 'typical' cervical vertebrae (C3–6). The ribbon-shaped muscle so formed is inserted into the basiocciput, the two muscles lying side by side in front of the foramen magnum alongside the pharyngeal tubercle. The muscles bulge slightly into the upper part of the nasopharynx. They are supplied segmentally by anterior rami of the upper four cervical nerves. Their action is to flex the skull and upper neck; they are weak because their action is assisted by gravity and by the powerful sternocleidomastoids.

Longus colli extends from the anterior tubercle of the atlas into the superior mediastinum. It consists of upper, lower and central fibres. The *upper fibres* connect the anterior tubercle of the atlas with the anterior tubercles of the transverse processes of C3–5 vertebrae. The *lower fibres* connect the bodies of T1–3 vertebrae with the anterior tubercles on the transverse processes of C5 and 6 vertebrae. The lateral border of this lower part

makes with the medial border of scalenus anterior a pyramidal space whose apex is the *carotid tubercle* (of Chassaignac) and whose base is the first part of the subclavian artery. In this space lie the vertebral artery and cervical sympathetic trunk with the stellate ganglion (Fig. 6.8). The *central fibres* of longus colli connect the bodies of C2–4 vertebrae with the remaining cervical and the upper three thoracic vertebrae (Fig. 6.6).

Longus colli is supplied segmentally by the anterior rami of the spinal nerves. It is a flexor of the neck, weak because it is aided by gravity and the strong sternocleidomastoids.

The *prevertebral fascia* is considered on page 423.

CERVICAL SYMPATHETIC TRUNK

The **cervical part** of the **sympathetic trunk** (Fig. 6.6) ascends from the thorax across the neck of the first rib, medial to the highest intercostal vein. It runs up medial to the vertebral artery and lies *in front of* the prevertebral fascia, to which it is attached by loose areolar tissue. It ends at the superior cervical ganglion. The trunk lies *behind* the carotid sheath, just medial to the vagus nerve.

The **superior cervical ganglion**, containing about 1 million cell bodies, is about 3 cm long and lies in front of the lateral mass of the atlas and axis. The **middle cervical ganglion** is a small, inconstant ganglion lying on the trunk medial to the carotid tubercle (C6 vertebra) and *in front of* the vertebral artery. The **inferior cervical ganglion** lies *behind* the commencement of the vertebral artery. A small mass when separate, it is more often fused with the first thoracic ganglion to form the **stellate ganglion**, properly called the **cervicothoracic ganglion**, a mass which may measure as much as 1 cm by 0.5 cm, lying in front of the neck of the first rib. The middle ganglion is connected to the inferior ganglion (or stellate ganglion when present) by a part of the trunk which passes in front of the subclavian artery, the *ansa subclavia* (Fig. 6.8). It often lies lower, and joins the inferior cervical to the first or second thoracic ganglion.

No white rami enter the ganglia from the cervical nerves: all the fibres ascend from the thoracic part of the trunk. As elsewhere, the branches of the ganglia are somatic and visceral in their distribution.

Somatic branches pass as grey rami to all eight cervical nerves. The superior ganglion gives grey rami to the first four (i.e. to the cervical plexus), the middle ganglion to the next two (5 and 6) and the inferior ganglion to the last two (7 and 8) anterior rami (i.e. to the brachial plexus for distribution to the upper limb).

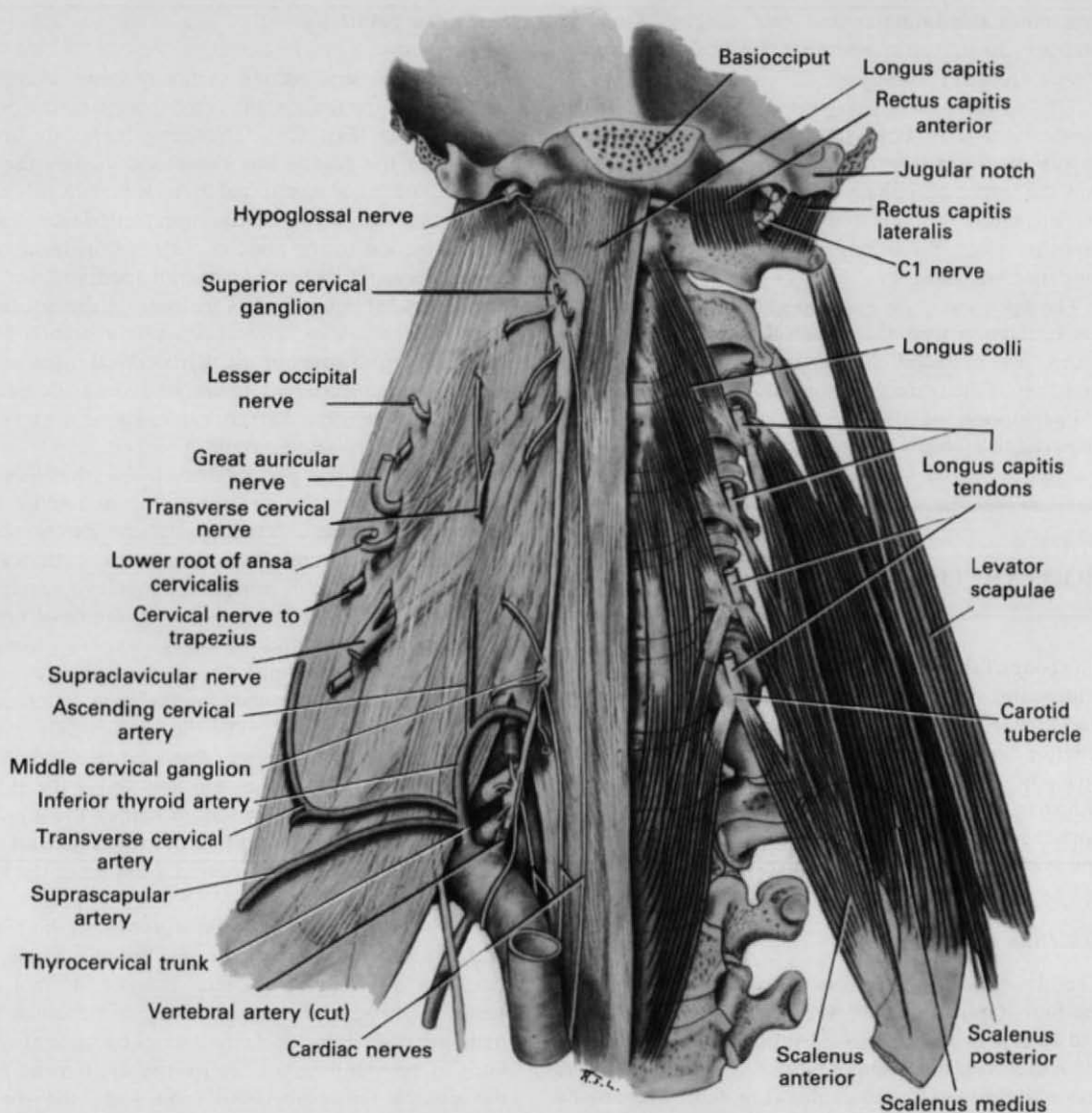


Fig. 6.6 Prevertebral region of the neck. The right half of the prevertebral fascia is intact; on the left the prevertebral muscles are exposed.

Visceral branches include a branch from each ganglion to the cardiac plexus. The branch from the upper left ganglion runs down to the superficial part, the other two left and all three right ganglionic branches all pass to the deep part. All six cardiac branches pass through the neck behind the common carotid artery and usually behind the subclavian artery to reach the superior mediastinum.

Vascular branches 'hitch-hike' their way along arteries. The *superior ganglion* gives branches to the

internal carotid and external carotid arteries. The one or more branches that accompany the internal carotid artery into the skull constitute the *internal carotid nerve*. As well as accompanying all branches of the artery the fibres (forming the *internal carotid plexus*) are distributed to the pterygopalatine ganglion and the eyeball, the latter including the motor supply of the dilator pupillae of the iris. The plexus on the external carotid artery accompanies all branches of the vessel and in addition supplies sympathetic fibres to the pharyngeal plexus

and the submandibular and otic ganglia. Thus the branches to the carotid arteries are both somatic and visceral in their distribution.

The *middle cervical ganglion* gives branches to the subclavian and inferior thyroid arteries — the latter supply the lower larynx, the trachea, the hypopharynx and the upper oesophagus. The branches to the subclavian artery are for only its local branches. The branches along the inferior thyroid artery are visceral only (not somatic).

The *inferior cervical ganglion* gives a large branch to the vertebral artery (the vertebral 'plexus') which runs with all the branches of that vessel. It supplies only the branches of the vertebral artery (no viscera).

Interruption of the cervical sympathetic pathway gives rise to *Horner's syndrome*, described on page 519.

PART 5

ROOT OF THE NECK

The **root of the neck** lies above the apex of the lung; to understand the former is to appreciate the relations of the latter. The key to the root of the neck is the scalenus anterior muscle (Fig. 6.7A). Study its relations precisely; they comprise almost all that needs to be known of the part. Thence pass to the thoracic inlet and note the structures that pass through it between the apices of the lungs.

Scalenus anterior

This flat muscle arises from the anterior tubercles of the four 'typical' cervical vertebrae (3–6), the lowest and largest being the carotid tubercle of the sixth. At these tubercles four slender tendons of origin lie end to end with those of longus capitis (Fig. 6.6). The muscle slopes forwards and laterally as it passes down to end in a narrow tendon attached to the scalene tubercle and adjacent ridge on the inner border and upper surface of the first rib. It belongs to the group of prevertebral flexor muscles of the neck, and with them is covered by a prolongation of prevertebral fascia, the foundation upon which the viscera of the neck gain their mobility.

Nerve supply. By separate branches from the anterior rami of C4, 5, 6 nerves.

Action. It is more important as a landmark than an active muscle. It assists in flexion and rotation of the neck, and helps to stabilize the first rib. Even in quiet respiration it shows some electromyographic activity.

Anterior relations

The *phrenic nerve* passes vertically down across the obliquity of the muscle, plastered thereto by the prevertebral fascia (Fig. 6.8). The nerve leaves the medial border of the muscle low down and crosses the subclavian artery and its internal thoracic branch behind the subclavian vein. Lying on the suprapleural membrane it passes medial to the apex of the lung, in front of the vagus nerve, to enter the superior mediastinum. The nerve not infrequently lies in front of the subclavian vein. The *ascending cervical artery* is a branch of the inferior thyroid artery or the thyrocervical trunk. It runs up on the prevertebral fascia medial to the phrenic nerve. The uninjected artery can easily be mistaken for the nerve in a dissecting room specimen.

In front of the prevertebral fascia the *transverse cervical* and *suprascapular arteries* (Figs 6.2 and 6.8) lie between the scalenus anterior and the carotid sheath (internal jugular vein). The *vagus nerve* in the carotid sheath passes down in front of the subclavian artery, on the right side giving off its *recurrent laryngeal* branch. The latter hooks around the artery and passes upwards. The vagus nerve inclines posteriorly and runs on the medial surface of the apex of the lung to enter the superior mediastinum. The *internal jugular vein* is surrounded by the inferior *deep cervical lymph nodes*. One of them, behind the vein and above the inferior belly of the omohyoid muscle, is named the *jugulomohyoid node*. It receives lymph from the tongue and other sites, and lies beneath the posterior border of the sternocleidomastoid (Fig. 6.57).

The **subclavian vein** lies in a groove on the first rib and, due to the slope of the rib, lies at a lower level than the insertion of scalenus anterior. It is a large vessel 1 cm or more in diameter, and maintains its diameter even in hypovolaemic states because of adherence to surrounding connective tissues. It runs below the clavicle and subclavius, and joins the internal jugular vein at the medial border of scalenus anterior; the thoracic duct on the left and the right lymph duct on the right enter the angle of confluence of the two veins. The vein is too low to be included among the contents of the posterior triangle (p. 439).

Catheterization. The right subclavian vein can be used for the placement of a central venous line, instead of the internal jugular (p. 439); it is preferred by many operators and is more comfortable for the patient. The usual approach is infraclavicular, from a point 2 cm below the midpoint of the clavicle along a line towards the jugular notch of the sternum. The needle pierces the clavipectoral fascia and enters the vein just behind the fascia. The commonest complications are

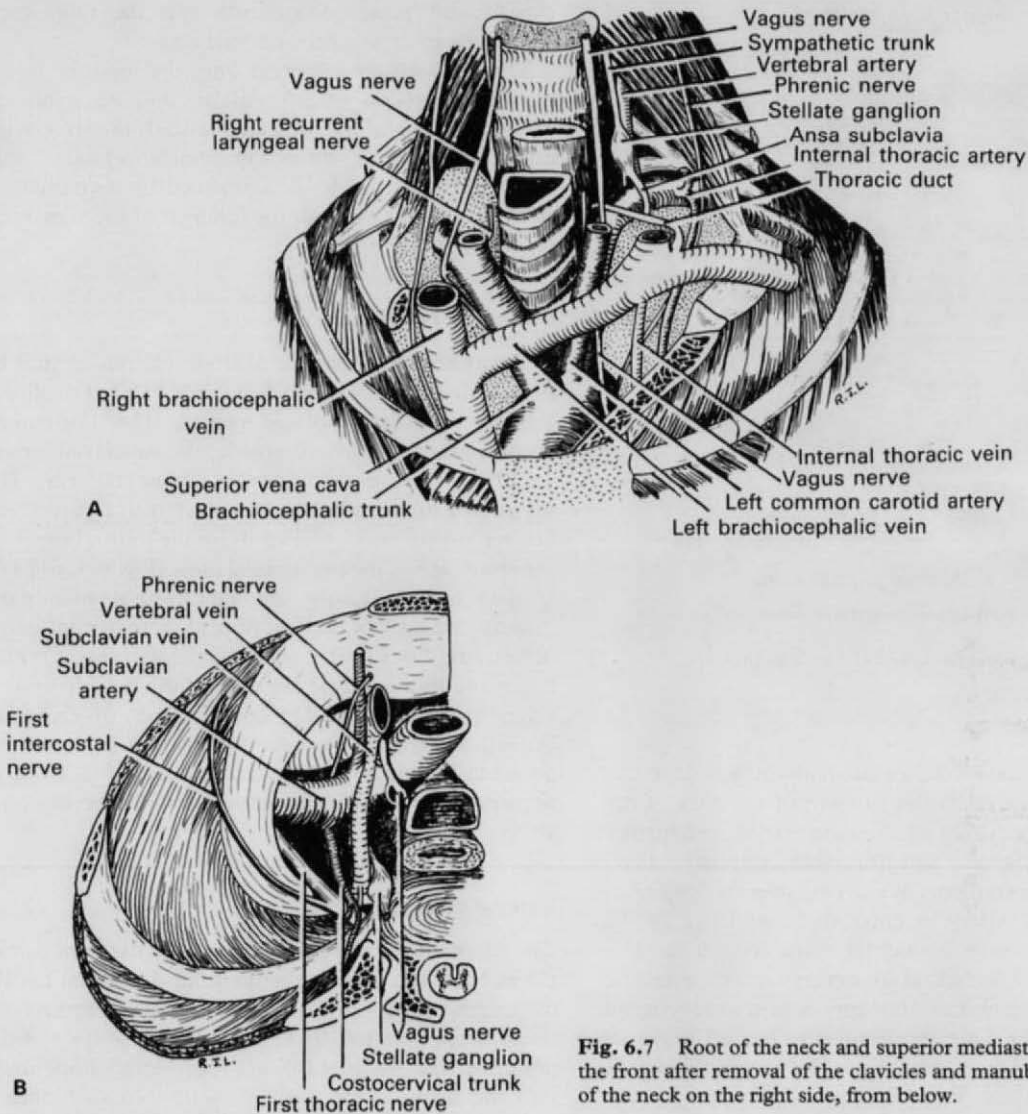


Fig. 6.7 Root of the neck and superior mediastinum. **A** From the front after removal of the clavicles and manubrium. **B** Root of the neck on the right side, from below.

pneumothorax due to puncture of the pleura and lung, and puncture of the subclavian artery. The vein is also used for the placement of wires from cardiac pacemakers, which are usually implanted in connective tissue over the upper lateral part of pectoralis major.

In front of the lower part of the carotid sheath runs the intermediate tendon of the omohyoid. All the structures enumerated above are covered in front by the lower part of the sternocleidomastoid muscle (Fig. 6.4).

Medial relations

The edge of *longus colli* runs up to the anterior tubercle

on the transverse process of C6 vertebra. It makes, with the medial edge of scalenus anterior, a pyramidal space; the base of the space is formed by the subclavian artery, and the neck of the first rib, between which lies the suprapleural membrane. Note that the apex of the pyramidal space is the carotid (Chassaignac's) tubercle (Figs 6.6 and 6.8), so named because the *common carotid artery* lies on it and can be there compressed. The common carotid artery, medial to the internal jugular vein, lies deep to sternocleidomastoid immediately in front of the pyramidal space.

The space contains the stellate ganglion and the vertebral artery and vein(s) (Figs 6.7A and 6.8). The

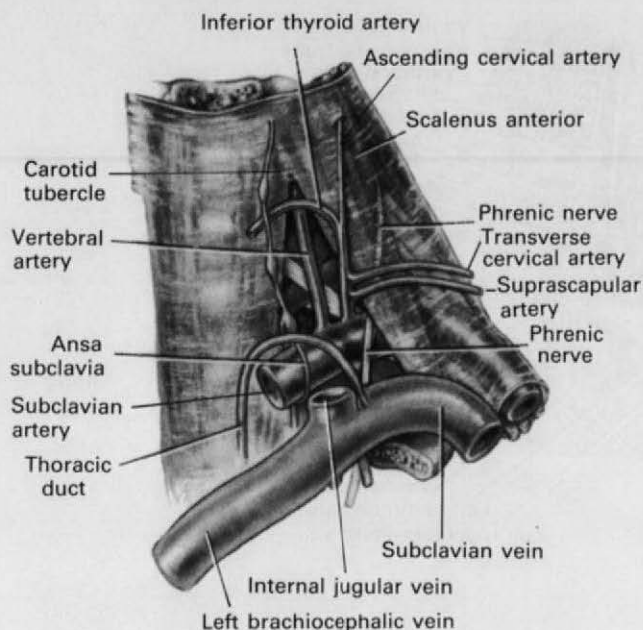


Fig. 6.8 Prevertebral fascia and the scalene muscles.

inferior thyroid artery arches medially in a bold curve whose upper convexity lies in front of the apex of the pyramidal space (C6 level). At a lower level, and further forward, the *thoracic duct* (or right lymphatic duct) makes a similar convexity as it arches over the lung apex and subclavian artery to enter the confluence of the subclavian and internal jugular veins (Fig. 6.8). The *first part* of the **subclavian artery** arches over the suprapleural membrane and impresses a groove upon the apex of the lung; it disappears behind scalenus anterior. It has three branches. The *vertebral artery* is the first; it arises from the upper convexity of the subclavian and passes up to disappear, at the apex of the pyramidal space, into the foramen of the transverse process of C6 vertebra. The sympathetic 'plexus' on the vertebral artery is often a single nerve that runs up behind the vessel. Medial but *anterior* to it lies the middle cervical ganglion, while medial but *posterior* to it and a little lower is the inferior cervical or stellate ganglion. A connecting loop between middle and inferior cervical ganglia passes in front of the subclavian artery, forming the *ansa subclavia*. The *thyrocervical trunk* arises lateral to the vertebral artery from the upper surface of the subclavian. It divides immediately into transverse cervical, suprascapular and inferior thyroid arteries, which have already been noted. The *internal thoracic artery* arises from the lower surface of the sub-

clavian and passes downwards over the lung apex, crossed by or crossing the phrenic nerve.

The *vertebral vein* emerges from the foramen in the transverse process of C6 vertebra and runs forward across the apex of the lung and beneath the subclavian artery to empty into the brachiocephalic vein (Fig. 6.7B). It may be accompanied by a companion vein that passes through the foramen of the transverse process of C7 vertebra.

Posterior relations

Scalenus anterior is separated from scalenus medius by the subclavian artery and the anterior rami of the lower cervical and first thoracic nerves. The last-named occupies the 'subclavian' groove, the subclavian artery usually lying somewhat further above the rib. The *second part* of the **subclavian artery** is that part which lies behind scalenus anterior. Here the fourth branch of the artery arises, the *costocervical trunk* (Fig. 4.5, p. 247). It passes back across the suprapleural membrane towards the neck of the first rib and there divides into a descending branch, the *superior intercostal artery*, which enters the thorax across the neck of the first rib and an ascending branch, the *deep cervical artery*, which passes beneath the transverse process of C7 vertebra and runs upwards behind the transverse processes, in front of semispinalis capitis, to anastomose with the occipital artery.

Lateral relations

The *trunks* of the **brachial plexus** and the *third part* of the **subclavian artery** emerge from the lateral border of scalenus anterior. They lie behind the prevertebral fascia, which plasters them down upon the floor of the posterior triangle (p. 426) and is projected along them into the axilla as the *axillary sheath*. No such sheath surrounds the axillary and subclavian veins; the latter lies in front of the prevertebral fascia and is free to dilate to accommodate an increased bloodflow. The *prevertebral fascia* is attached to bone at the edge of longus colli and is projected down from above over scalenus anterior, being attached to its medial border. There is no fascial roof across the pyramidal space between the two muscles and the subclavian artery by passing in behind scalenus anterior passes behind the lateral expansion of the prevertebral fascia (Fig. 6.8). The fifth and last branch of the artery, the *dorsal scapular*, usually arises from this part (though sometimes from the second part). It runs laterally in front of scalenus medius and through the brachial plexus, and then disappears deep to levator scapulae to

take part in the scapular anastomosis (p. 74). It is frequently replaced by the deep branch of the transverse cervical artery, and this branch then takes the name of dorsal scapular. Occasionally, the transverse cervical or suprascapular artery or both arise from the third part of the subclavian artery (that is, behind the prevertebral fascia), in which case they pass laterally between the trunks of the brachial plexus.

The *surface marking* of the subclavian artery in the neck is along a line arching upwards from the sternoclavicular joint to the middle of the clavicle and about 2 cm above it.

Surgical approach. The artery can be exposed by detaching the clavicular head of sternocleidomastoid from the clavicle and then detaching scalenus anterior from the first rib, taking particular care not to damage the phrenic nerve.

Scalenus medius and scalenus posterior

Scalenus medius arises from the posterior tubercles and intertubercular lamellae of all the cervical vertebrae and is inserted into the quadrangular area between the neck and subclavian groove of the first rib (Fig. 4.39, p. 292).

Scalenus posterior arises from the posterior tubercles of the lower cervical vertebrae, passes across the outer border of the first rib deep to the upper digitation of serratus anterior, and is inserted into the second rib along its outer border, behind the serratus anterior attachment.

Nerve supplies. Both muscles are supplied segmentally by the anterior rami of the lower cervical nerves, scalenus medius by C3–8 and scalenus posterior by C6–8.

Actions. Both muscles are mainly lateral flexors of the neck, but can act as elevators of the ribs and thus as accessory muscles of respiration.

Actions. They are mainly lateral flexors of the neck, and can act as accessory muscles of respiration.

The root of the neck is *floored* in by the suprapleural membrane (p. 248) to which the dome of the parietal pleura is attached. Many of the structures studied above form relations of the apex of the lung (Fig. 6.7B).

The midline structures in the root of the neck consist of trachea and oesophagus (p. 433) the thoracic duct (p. 444) and the recurrent laryngeal nerves. These nerves run up in the groove between trachea and oesophagus, and their relationships to the thyroid gland and its inferior arteries have been described (p. 431). They give branches to the cervical parts of oesophagus and trachea and to the cricopharyngeus, and enter the

lower part of the pharynx below the inferior border of cricopharyngeus (Fig. 6.30).

PART 6 FACE

The **face** is the part of the front of the head between the ears and from the chin to the hairline (or where it ought to be if you have lost it!). The **facial skeleton** is the front part of the skull, including the mandible, described on page 647. The major openings are the two orbits, the piriform (anterior nasal) aperture, and the oral aperture between the jaws. The supraorbital, infra-orbital and mental foramina lie in approximately the same vertical plane.

SKIN OF THE FACE

Tension lines in facial skin tend to run in an 'onion skin' pattern from mouth to ear (Fig. 1.2, p. 3). Senile facial wrinkles lie at right angles to the line of pull of the underlying muscles (horizontal wrinkles on the brow, 'crow's foot' wrinkles at the lateral canthus, vertical wrinkles on both lips). Incisions along these wrinkles heal with minimal scarring.

MUSCLES OF THE FACE

Embryologically the muscles of 'facial expression' are developed from the mesoderm of the second pharyngeal arch, from which they migrate widely to their adult positions. They are supplied by the nerve of the second arch, the seventh cranial (facial) nerve. They are, *morphologically*, specialized members of the panniculus carnosus (p. 3). The essential point here is that the panniculus carnosus is in places attached to the dermis, which it therefore wrinkles or dimples. There is no deep fascia on the face.

Functionally the muscles are differentiated to form groups around the orifices. The orifices of orbit, nose and mouth are guarded by eyelids, nostrils and lips and there is a *sphincter* and an opposing *dilator* arrangement peculiar to each. The purpose of the facial muscles is to control these orifices. The varying expressions so produced on the face are side effects; man has educated himself to be particularly sensitive to minor changes of expressions so produced on the faces of his fellows. Some of the muscles supplied by the facial nerve are incapable of affecting the expression of the face; moreover, certain facial expressions full of meaning are produced by muscles (e.g. levator

palpebrae superioris, ocular muscles, tongue) not supplied by the facial nerve. Normal facial appearances have little to do with the underlying muscles; we all have the same muscles but how different we all look, unless we are identical twins! It is the contour of the overlying connective tissues and the way they are connected to the muscles (determined by genetic expression) which produce the end result. The muscles of 'facial expression' are best understood and remembered by appreciating their functional arrangement around the orbits, nose and mouth (Fig. 6.9), and it is strongly recommended that the muscles be studied in these functional groups.

Muscles of the eyelids

The palpebral fissure is surrounded by a sphincter, the orbicularis oculi, and has a dilator mechanism

consisting of levator palpebrae superioris (considered with the orbital muscles, p. 508) and occipitofrontalis which is part of the scalp (p. 453).

Orbicularis oculi is rightly described in two parts, the palpebral part, confined to the lids, and the orbital part, extending beyond the bony orbital margins on to the face. The **palpebral part** consists of fibres that arise from the medial palpebral ligament and arch across both lids, anterior to the tarsal plates, and are inserted into the lateral palpebral raphe. Some of the lower fibres are attached medially to the posterior lacrimal crest and the lacrimal sac itself. The **orbital part**, much the larger, arises from the anterior lacrimal crest and the frontal process of the maxilla, whence the fibres circumscribe the orbital margin in a series of concentric loops. The muscle lies flat over the forehead and cheek (frontal and zygomatic bones).

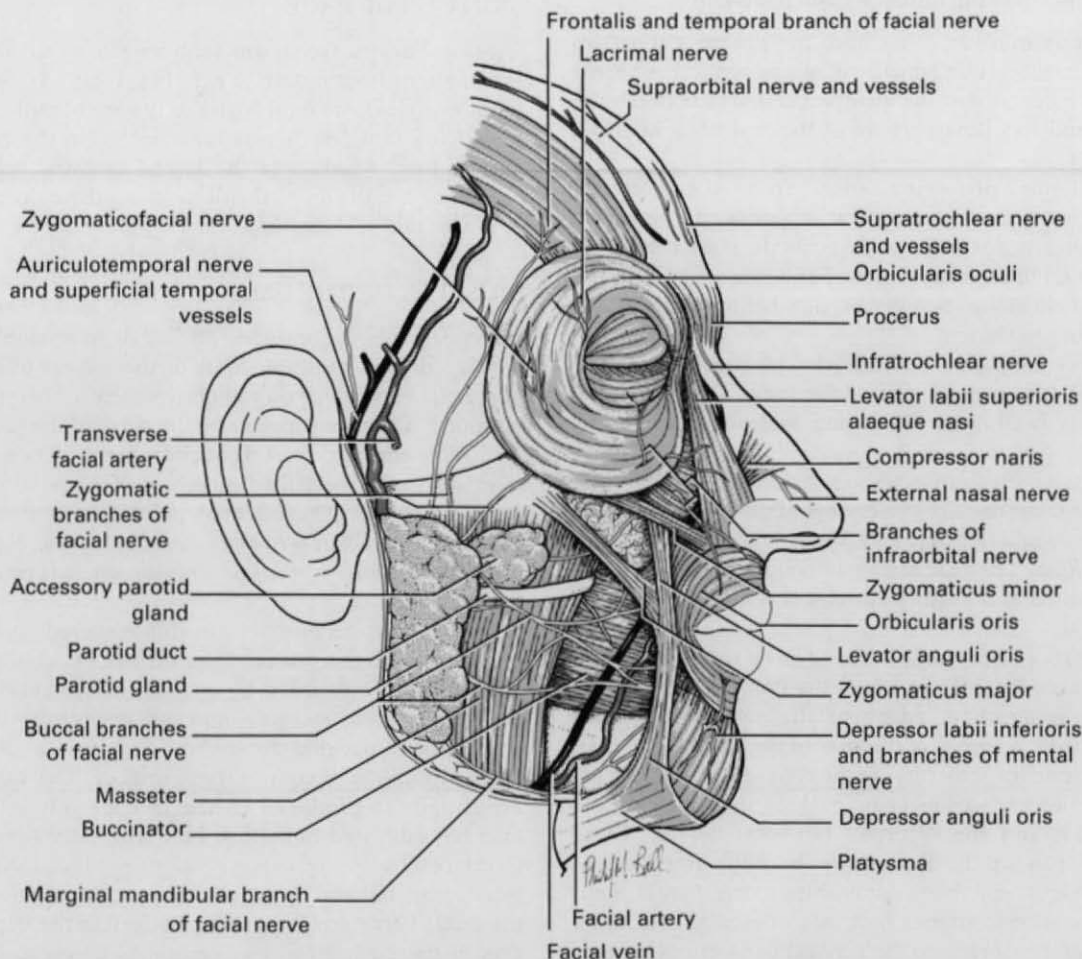


Fig. 6.9 Superficial dissection of the side of the face.

Nerve supply. By temporal and zygomatic branches of the facial nerve.

Action. Contraction of the palpebral fibres closes the lids gently without burying the eyelashes, and stretches the lacrimal sac (p. 508). This movement of 'blinking' does not diminish the volume of the conjunctival sac, and even when the eye is brimful of tears none are spilt when the eyelids close. When the orbital part contracts it lowers the eyebrow, to shade the eye from a light that is too bright from above. Orbital and palpebral parts contracting together close the eyelids forcibly so that the eyelashes are buried and only their tips are visible. This movement ('screwing up the eyes') diminishes the volume of the conjunctival sac, and causes an eye that is brimful of tears to spill out over the cheek. In normal closing of the eye, the lateral part of the upper lid comes down before the medial part, so helping to spread lacrimal secretion from the gland side (lateral) towards the nose.

Levator palpebrae superioris is the opponent of the sphincter of the palpebral fissure, i.e. of the palpebral fibres of orbicularis oculi. It is described with the orbital muscles (p. 509).

Occipitofrontalis is considered with the scalp on page 453.

Muscles of the nostrils

The sphincter muscle of the nostril is the transverse part of nasalis (**compressor naris**), which embraces the alar cartilages, and its opponent is the alar part of nasalis (**dilator naris**), which is inserted into the lateral part of the ala. Each arises from the maxilla. The nose, in addition, can be elevated somewhat by procerus and levator labii superioris alaeque nasi and depressed by the depressor septi, much weaker because its action is assisted by elastic recoil of the nasal cartilages. All are supplied by zygomatic and buccal branches of the facial nerve.

Muscles of the lips and cheeks

The sphincter is the orbicularis oris; the dilator mechanism consists of the remainder of the facial muscles, which radiate outwards from the lips like the spokes of a wheel.

Orbicularis oris consists of fibres proper to itself, attached near the midline to upper and lower jaws, and fibres that are added to these from the dilator muscles. The intrinsic fibres are attached to bone near the midline and well away from the alveolar margin. The *incisive* and *mental slips* curve around the angle of the mouth in a loop on either side (Fig. 6.10). They are the

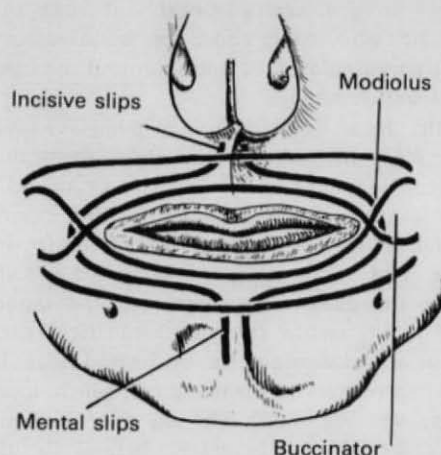


Fig. 6.10 Fibres of orbicularis oris.

deepest of all the orbicularis fibres and the mucous membrane of the lips is firmly attached to them. They are only a thin sheet. The bulk of the orbicularis muscle is formed of extrinsic fibres; most of these come from the buccinator. The fibres of buccinator converge towards the modiolus. At the modiolus they form a chiasma; the uppermost and lowermost fibres pass straight on into their respective lips, while the middle fibres decussate, the upper fibres of buccinator passing into the lower lip, the lower into the upper lip.

Nerve supply. By buccal and marginal mandibular branches of the facial nerve. It is damage to the latter branch (in the surgical approach to the submandibular gland) that causes an unsightly drooping of the corner of the mouth.

Action. Contraction of the orbicularis oris causes a narrowing of the mouth, the lips becoming pursed up into the smallest possible circle (the whistling expression).

Buccinator has a bony origin from both jaws opposite the molar teeth, and from the pterygomandibular raphe. Examine the vestibule of the mouth opposite the molars with tongue and finger. The buccinator arises just beyond the buccogingival fold; note its distance from the gum margin. Examine a skull and mark out the origin. Commencing at the anterior border of the first molar of the upper jaw, well away from the alveolar margin, the line passes horizontally backwards, skirting the root of the zygomatic process, and curves downwards to the tuberosity of the maxilla. Here there is a gap in the bony origin, the muscle arising from a fibrous band (sometimes called the *pterygomaxillary ligament*, and not to be confused with the pterygomandibular raphe) that extends from the tip of

the hamulus to the nearest part of the tuberosity of the maxilla. Through the gap above this band passes the tendon of tensor palati as it hooks around the base of the hamulus (Fig. 6.11).

From the tip of the hamulus the *pterygomandibular raphe* extends to the mandible just above the posterior end of the mylohyoid line. The buccinator arises from the whole length of the raphe, along which it interdigitates with the fibres of the superior constrictor (p. 487); the raphe is passively elongated when the mouth is open. The mandibular attachment of the raphe is separated by a narrow interval from the posterior attachment of mylohyoid to the mylohyoid ridge; here the lingual nerve rests on the mandible, which, indeed, it often grooves (Fig. 6.26). The line of attachment of buccinator should now be traced behind the third molar (across the retromolar fossa) to the oblique line of the mandible; it then runs down just above this line as far forwards as the anterior border of the first molar. The muscle converges on the modiolus (p. 449), where its fibres of origin from the raphe decussate; the maxillary and mandibular fibres pass medially without decussation into the upper and lower lips respectively. The outer surface of the muscle is pierced by the parotid duct opposite the *third* upper molar tooth. The duct also passes through the buccal fat pad which lies on the outer surface of buccinator and is particularly promi-

nent in infants, giving them their chubby cheeks. Beneath the fat lie the *molar glands*, four or five nodules each the size of a split pea. Their ducts pierce the muscle to open on the mucous membrane of the cheek (which lines the muscle's inner surface) opposite the third upper molar tooth.

Nerve supply. By the buccal branches of the facial nerve. It belongs developmentally to the facial expression group, hence its nerve supply by this (second arch) nerve. Although filaments from the buccal branch of the mandibular nerve pierce the muscle to supply the oral mucous membrane overlying it, they are only proprioceptive as far as buccinator is concerned. Thus it is vitally important to distinguish between the buccal branches of the *facial* nerve which are the *motor* supply, and the buccal branch of the *mandibular* which is *afferent* only.

Action. It is essentially an accessory muscle of mastication, being indispensable to the return of the bolus from the cheek pouch to the grinding mill of the molars. It is only a muscle of facial expression in so far as it belongs to the group supplied by the facial nerve, but it is equally important not to classify it as a proper 'muscle of mastication' (like masseter, temporalis and the two pterygoids) which have their motor supply from the mandibular branch of the trigeminal nerve. Buccinator helps to keep food out of the vestibule of the

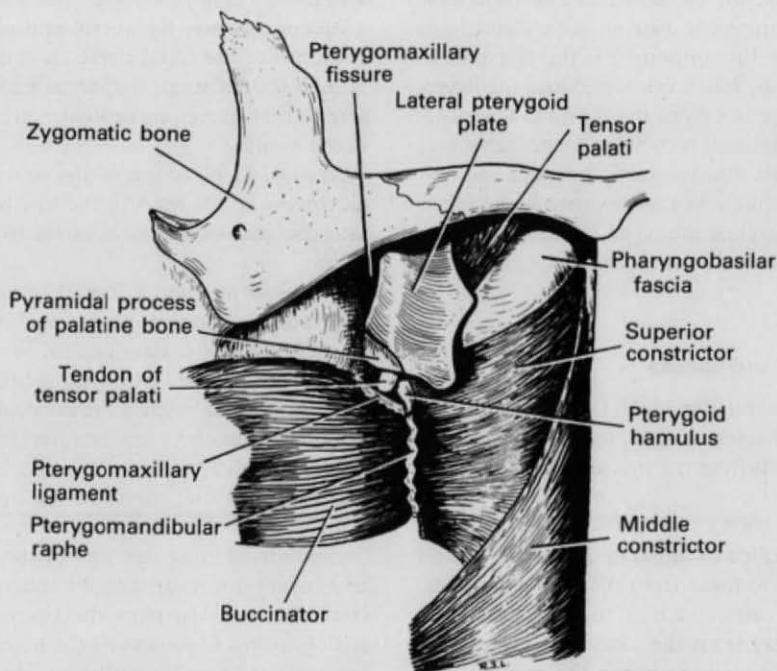


Fig. 6.11 Attachments of the left pterygoid hamulus.

mouth and in between the teeth; it does not move the jaw. When the cheeks are puffed out the muscle is relaxed. Only in forcible expulsion of air from the mouth, as in blowing a trumpet, are the elongated fibres of the puffed out cheeks under contraction. Otherwise contraction of the muscle obliterates the cavity of the vestibule and pulls the closed lips tightly back against the teeth.

Dilator muscles of the lips

Radiating from orbicularis oris like the spokes of a wheel is a series of dilator muscles, some inserted into the lips, some into the modiolus. All contracting together open the lips into the widest possible circle, an action that is usually accompanied by simultaneous opening of the jaws. Upper and lower lips have flat sheets of elevator and depressor muscles. Other muscles converge towards the angle of the mouth, where their decussating fibres build up, with the chiasma in the buccinator fibres, a knot of muscle known as the **modiolus** (Fig. 6.10). The intersecting fibres cannot slip through the modiolus, for at their crossing they are bound together by fibrous tissue. Thus the modiolus (and the angle of the mouth) can be moved about. The modiolus lies just lateral to the angle of the mouth, opposite the second upper premolar tooth. Its position and movements are of great importance in prosthetic dentistry. The individual dilator muscles are of little practical importance; only their chief features are summarized here.

Traced from the nose laterally a continuous sheet of elevator fibres comprises two separate muscles. **Levator labii superioris alaeque nasi** arises from the frontal process of the maxilla and is inserted into the alar cartilage and the upper lip; it elevates both. **Levator labii superioris** arises from the inferior orbital margin and is inserted into the remainder of the upper lip, which it elevates. The muscle overlies the exit of the infraorbital nerve. From the canine fossa below the infraorbital margin arises **levator anguli oris**; the infraorbital nerve lies sandwiched between it and the overlying levator labii superioris. The fibres of this muscle, deep to the superficial sheet of muscle, converge to the modiolus and pass through it to become superficial. They merge into the fibres of depressor anguli oris. **Zygomaticus minor** from the zygomaticomaxillary suture and **zygomaticus major** further out on the surface of the zygomatic bone converge to the modiolus. **Risorius** is a variable muscle, an upward extension from the platysma. It converges on the modiolus, with a gap above and below it exposing the facial artery and its companion vein. **Depressor anguli oris** arises from the

oblique line of the mandible. It lies superficial; its fibres pass through the modiolus to the deeper stratum (levator anguli oris). **Depressor labii inferioris** arises deep to the former muscle. It is quadrangular in shape; its fibres are inserted into the lower lip. **Mentalis** is a muscle that arises from the symphysis menti near the midline of the mandible. Its fibres pass downwards through the depressor labii inferioris to reach the skin. It is an elevator of the skin of the chin (which it sometimes dimples) and thus of the centre of the lower lip and its contraction may disturb a lower denture.

Nerve supply of face muscles

All the muscles thus far described receive their motor supply from the **facial nerve**. This nerve contains no sensory fibres on the face and *proprioceptive* impulses from the facial muscles are conveyed centrally by the *trigeminal* nerve, whose cutaneous branches intermingle freely on the face with branches of the facial nerve. A muscle supplied by the facial nerve receives its *proprioceptive innervation* from branches of the sensory nerve supplying the *skin over the muscle*. On the face itself branches of the trigeminal nerve provide the afferent innervation for all the muscles. That for platysma is supplied by the transverse cervical nerve, which lies beyond the cutaneous distribution of the trigeminal nerve.

The **facial nerve** emerges from the base of the skull through the stylomastoid foramen, near the origin of the posterior belly of digastric. It immediately gives off the **posterior auricular nerve** which passes upwards behind the ear to supply the occipital belly of occipitofrontalis. A **muscular branch** is next given off which divides to supply the posterior belly of digastric and stylohyoid. The nerve now approaches the posteromedial surface of the parotid gland. Just before entering the gland it divides into upper *temporozygomatic* and lower *cervicofacial* branches. Within the substance of the parotid gland each divides and rejoins to divide again and finally emerge from the parotid gland in five main groups of branches (Fig. 6.12). This plexiform arrangement, the **pes anserinus**, lies in the gland superficial to the retromandibular vein and the external carotid artery. Place the heel of the hand over the parotid gland, thumb on the temple, little finger down the neck. The five digits indicate the five branches of the nerve, or rather groups of branches, for the first three are usually multiple.

The **temporal branches** emerge from the upper border of the gland, cross the zygomatic arch, and supply auricularis anterior and superior, and part of frontalis. They are only important for wrinkling the forehead.

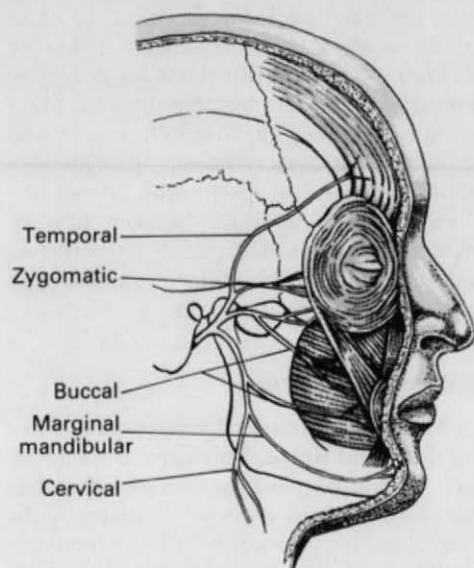


Fig. 6.12 Facial branches of the right facial nerve.

The **zygomatic branches** consist of upper and lower parts, which proceed above and below the eye. The upper branches supply frontalis and the upper half of orbicularis oculi. They cross the zygomatic arch and may be divided in incisions for operations on the temporal fossa, or injured in fractures of the zygomatic arch. The lower branches supply the lower half of orbicularis oculi and the muscles below the orbit. Two or three branches pass to both upper and lower lids. Paralysis prevents blinking, the precorneal film of tears is no longer spread, and the dry cornea ulcerates. The resultant scar impairs vision.

The **buccal branches** supply buccinator and the muscle fibres of the upper lip (i.e. orbicularis oris and the lower fibres of the elevators). Paralysis prevents emptying of the cheek pouch; the bolus lodges there and cannot be returned to the molar teeth. Chewing has to be performed on the other side.

The **marginal mandibular branch** supplies the muscles of the lower lip. It is important to remember that this nerve emerges from the lower border of the parotid gland and in 20% of cases passes *into the neck* below the angle of the mandible. It crosses the inferior border of the bone to reach the face beyond the anterior border of the masseter muscle, crossing the facial artery and vein. A small lymph node lies here and an incision of an abscess in the node can result in permanent paralysis of the lower lip. The nerve is in danger when an incision is made along the lower border of the mandible (p. 437).

The **cervical branch** passes vertically downwards from the lower border of the parotid gland behind the mandible and supplies platysma. The marginal mandibular branch occasionally arises from it below the parotid gland, a fact which apparently originated the erroneous though common statement that the muscles of the lower lip are supplied by the cervical branch of the facial nerve.

SENSORY NERVE SUPPLY OF THE FACE

The skin of the face is supplied in three zones by branches of the three divisions of the trigeminal nerve. The three zones meet at the margins of the eyelids and the angles of the mouth; the lines of junction of the zones curve upwards. This arrangement is developmental. The areas of skin supplied by the three branches of the trigeminal nerve originally met each other along lines that extended horizontally back from the angles of the eye and mouth. The skin supplied by the mandibular nerve (the lowest branch of the trigeminal) lay over the mandible. The area now supplied by its auriculotemporal branch was first over the angle of the mandible. As the cranial cavity expands over the growing brain it draws face skin over it, so that beard skin is drawn up over the temple, and neck skin is drawn up to replace it. The temple is so named because, by its greying hairs, it is the first part to show the passage of time ('Tempus fugit'). The only part of the facial skin not supplied by any branch of the trigeminal nerve is that over the angle of the mandible and for some distance above and in front of it; this area is supplied by the great auricular nerve (p. 427).

The muscles of the face are supplied with proprioceptive fibres by these same cutaneous nerves, which make multiple junctions with the branches of the facial nerve on the face.

The **trigeminal nerve** has three divisions (officially called branches) — ophthalmic, maxillary and mandibular (p. 43) — and each gives respectively five, three and three cutaneous branches, distributed as in Figure 6.13A. The pattern of a *facial haemangioma* (portwine stain, as in the Sturge-Weber syndrome), or of the skin rash of herpes zoster affecting the trigeminal ganglion, often affords an accurate demonstration of the area of skin supplied by one or more of the main branches of the nerve. In herpes the mandibular nerve is less often affected than the other two. Clinical observations indicate that, as far as pain fibres in the trigeminal nerve are concerned, the fibres are arranged in an 'onion-skin' pattern with respect to the cells of the spinal nucleus of the trigeminal nerve with which they synapse (p. 631). The area round the mouth and lower part of the nose is

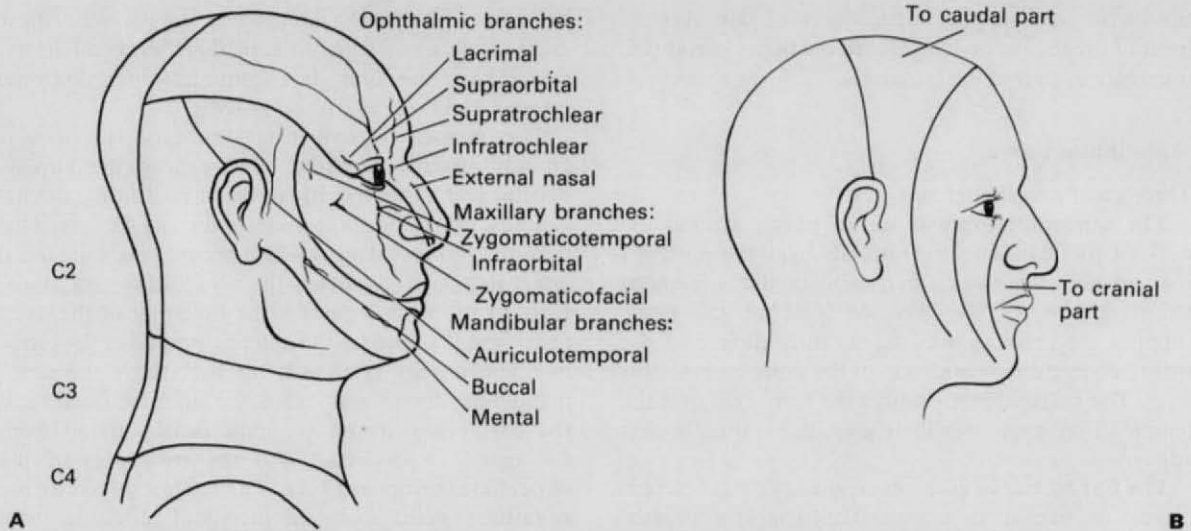


Fig. 6.13 Dermatomes and cutaneous nerves of the right side of the head and neck. **A** Dermatomes and trigeminal nerve branches. **B** 'Onion-skin' representation of the facial areas in the spinal nucleus of the trigeminal nerve. Fibres from the most anterior part of the face synapse with cells of the most cranial part of the nucleus.

supplied by fibres that synapse with cells in the highest (pontine) part of the spinal nucleus, followed by concentric areas, as in Figure 6.13B, whose fibres pass to progressively lower levels of the nucleus. It seems that the onion-skin arrangement for pain does not correspond exactly to the sensory distribution of the main nerves (compare Figs 6.13A and B).

Ophthalmic nerve

Five cutaneous branches:

The **lacrimal nerve** supplies a small area of skin over the lateral part of the upper lid.

Towards the medial end of the upper margin of the orbit the **supraorbital nerve** indents the bone into a notch or a foramen. The nerve passes up, breaking into half a dozen or more branches which radiate out and supply the forehead and scalp up to the vertex.

The **supratrochlear nerve** passes up on the medial side of the supraorbital nerve through the frontal notch or foramen and divides to supply the middle of the forehead up to the hairline. Above this the supraorbital nerves meet in the midline up to the vertex.

The **infratrochlear nerve** supplies skin on the medial part of the upper lid and, passing above the medial palpebral ligament, descends along the side of the external nose, supplying skin over the 'bridge' of the nose. It supplies no skin of the lower lid, which is second division territory.

These four branches of the ophthalmic nerve also supply upper lid conjunctiva.

The **external nasal nerve** supplies the middle of the external nose down to the tip. It emerges between the nasal bone and the upper nasal cartilage. In herpes zoster, involvement of this branch of the nasociliary nerve (p. 513) suggests that the cornea (supplied by the ciliary branches of the same nerve) may also become affected and lead to dangerous corneal ulceration.

Maxillary nerve

Three cutaneous branches:

The **infraorbital nerve** emerges through its foramen and lies between levator labii superioris and the deeper placed levator anguli oris. It is a large nerve that immediately breaks up into a tuft of branches; these radiate away from the foramen to supply *palpebral branches* to the lower eyelid and cheek, *nasal branches* to the side and ala of the nose, and *labial branches* to the upper lip and the labial gum from the midline to include the gum over the second premolar tooth. Many twigs join nearby branches of the facial nerve for the proprioceptive supply of adjacent face muscle.

The **zygomaticofacial nerve** emerges from a foramen on the outer surface of the zygomatic bone; its branches supply the overlying skin.

The **zygomaticotemporal nerve** emerges in the *temporal fossa* through a foramen in the temporal (posterior) surface of the zygomatic bone. It makes its way to

the surface and supplies a small area of skin over the front of the temple on a level with the upper eyelid (i.e. the 'hairless' part of the temple).

Mandibular nerve

Three cutaneous branches:

The **auriculotemporal nerve** passes around the neck of the mandible and ascends over the posterior root of the zygomatic arch behind the superficial temporal vessels. The *auricular* part of the nerve supplies the external acoustic meatus, surface of the tympanic membrane and skin of the auricle above this level. The *temporal* part supplies the hairy skin over the temple, that part in which grey hairs usually first appear.

The **buccal nerve** gives off cutaneous twigs before it pierces the buccinator muscle. They supply a 'thumb-print' area over the cheek just below the zygomatic bone, between the areas of the infraorbital nerve and the great auricular nerve (p. 427).

The **mental nerve** is a cutaneous branch of the inferior alveolar nerve. Like the infraorbital nerve it breaks up into a tuft of branches that radiate away from the mental foramen to supply the skin and mucous membrane of the lower lip and labial gum from the midline to about the second premolar tooth.

BLOOD SUPPLY OF THE FACE

The **facial artery** is the highest of the three branches that issue from the anterior aspect of the external carotid artery. It passes upwards on the side wall of the pharynx and hooks downwards over the posterior belly of digastric to come into contact with the upper surface of the submandibular gland (p. 436). It then hooks upwards over the inferior border of the mandible at the anterior border of the masseter muscle. It pursues a tortuous course towards the medial angle of the eye, lying deep to the sheet of dilator muscles that radiate out from the lips. It is visible only in the interval above and below the zygomatic and risorius muscles. Its labial branches are important; one for each lip, each **superior** and **inferior labial artery** divides into two, each of which runs across the lip beneath the red margin, one in front and the other behind. They anastomose end to end at the midline. The severed artery spurts from both ends. The temple is supplied by the **superficial temporal artery**, a terminal branch of the external carotid. At its beginning it gives off the **transverse facial artery**, which runs across the cheek just above the parotid duct. The forehead is supplied from the orbit by the **supraorbital** and **supratrochlear**

branches of the ophthalmic artery. In the scalp these anastomose freely with the superficial temporal artery, establishing the only free communication between internal and external carotid systems.

The **venous return** from the face is normally entirely superficial. From the forehead the **supra-orbital** and **supratrochlear veins** pass to the medial canthus, where they unite to form the *angular vein*. This becomes the **facial vein** which accompanies the facial artery to a point just below the border of the mandible. Here in the neck it pierces the investing of the deep fascia and is joined by the anterior branch of the retromandibular vein. (Formerly the part above the retromandibular union was called the anterior facial, and the part below it the common facial.) Blood from the temple is collected into the tributaries of the **superficial temporal vein**. The latter is joined by the **maxillary veins** from the pterygoid plexus to form the **retromandibular vein**. This passes downwards in the substance of the parotid gland and on emerging from its lower border divides into anterior and posterior branches. The *anterior branch* joins the facial vein which empties into the internal jugular. It often receives the superior thyroid vein and the vena comitans of the hypoglossal nerve. The *posterior branch* pierces the investing layer of deep cervical fascia and is joined by the posterior auricular vein to form the **external jugular vein**. This courses down in the subcutaneous tissue over sternocleidomastoid and pierces the investing layer of deep cervical fascia a finger's breadth above the midpoint of the clavicle, to empty into the subclavian vein; it has valves about 4 cm above the clavicle.

Deep venous anastomoses

The facial vein communicates with the **cavernous sinus** (p. 564). At the medial canthus there is a communication with the **ophthalmic veins**, which drain directly into the sinus. Blood from the forehead normally flows via the facial vein; if the latter is blocked by pressure or thrombosis blood above the obstruction will flow through the orbit into the cavernous sinus. Hence the 'danger area' of infection of the upper lip and nearby cheek. A further communication is the **deep facial vein**. This passes, in front of the masseter muscle, between the facial vein and the pterygoid plexus. The plexus receives a vein from the cavernous sinus through the foramen ovale or, if present, the venous foramen (of Vesalius), a small hole medial to the foramen ovale (p. 651). The danger area of the face lies between the angular and deep facial veins.

LYMPH DRAINAGE OF THE FACE

The face drains into three superficial groups of nodes (p. 522) from three wedge-shaped blocks of tissue. Centrally the chin and tip of the tongue drain into **submental nodes**. A wedge of tissue above this drains to **submandibular nodes**; this wedge extends from central forehead and frontal sinuses through the anterior half of the nose and maxillary sinuses to the upper lip and lower part of the face, and includes the tongue and the floor of the mouth. Beyond the second wedge, forehead, temple, orbital contents and cheek drain to the preauricular group, and eventually all lymph reaches deep cervical nodes.

PART 7 SCALP

The **scalp** extends from the eyebrows to the highest nuchal lines at the back of the skull and down to the ears and zygomatic arches at the sides. The **forehead**, from eyebrows to hairline (or where it should be if it has receded) is common to the face and scalp. The composition of the scalp is traditionally recalled from the five letters of the word which indicate its five layers — Skin, Connective tissue, Aponeurosis with muscle at the front and back, Loose areolar tissue and Pericranium.

The **skin** of the scalp is the thickest in the body, varying from 3–7 mm (body average 1–2 mm), and is thickest of all in the occipital region. Apart from being the hairiest part of the body it also contains a high concentration of sebaceous glands. Many of the fibres of the scalp muscle are inserted into it. Elsewhere it is firmly attached by *dense connective tissue* (the second layer) to the underlying *muscle and aponeurosis*. The blood vessels run within this firm tissue which unites the first and third layers. The tissue of the fourth layer is very *loose*, enabling the layers above to move over the *pericranium*, which is the name given to the periosteum of the vault of the skull. This is rather loosely attached to the bone and is easily stripped up by a subperiosteal haematoma. Such a haematoma outlines the bone concerned, since the pericranium is very firmly attached at the sutures.

Occipitofrontalis consists of occipitalis and frontalis muscular parts on each side and a central *epicranial aponeurosis* (*galea aponeurotica*) into which they are inserted at the back and front respectively. *Occipitalis* arises from the highest nuchal line and passes forwards into the aponeurosis which lies over the top of

the skull. The aponeurosis fades out laterally by blending with the temporalis fascia just above the zygomatic arch. *Frontalis* arises from the front of the aponeurosis and passes forwards to become attached to the upper part of orbicularis oculi and the overlying skin of the eyebrow. The right and left frontalis muscles meet in the midline, but the two occipitalis muscles do not join one another. Note that only occipitalis has a bony attachment; frontalis runs between aponeurosis, muscle and skin but not bone.

Nerve supply. By the facial nerve; the posterior auricular branch to occipitalis, and temporal and zygomatic branches to frontalis.

Action. While occipitalis can pull the scalp back in certain individuals, usually it merely anchors the aponeurosis while frontalis elevates the eyebrows and produces wrinkles in the skin of the forehead. The scalp muscles are the opponents of the orbital part of orbicularis oculi; thus the scalp may be regarded as an upward prolongation of the face that extends back to the occiput.

Beneath the muscles and aponeurosis is a small amount of loose areolar tissue providing a plane above which the rest of the scalp can move and through which avulsion can occur (scalping). This so-called fourth layer really forms a subaponeurotic space, limited behind by the attachments of occipitalis to the nuchal lines and at the sides by the blending of the aponeurosis with the temporalis fascia. In front the space extends down beneath orbicularis oculi into the eyelids. Bleeding anywhere beneath the aponeurosis may appear as a 'black eye' by the blood tracking down through the space.

Blood supply

The arteries of the scalp are derived from the external carotid artery by the occipital, posterior auricular and superficial temporal branches, and from the internal carotid artery by the supratrochlear and supraorbital branches. *All these arteries anastomose very freely with each other.* The junction of forehead and temple, above the outer end of the eyebrow, is the area where the external and internal carotid branches anastomose most freely with each other. The arteries are attached to the deepest layer of the dermis, and in a scalp wound they bleed profusely because the cut vessel ends remain held open. From the richly-anastomosing skin arteries very few branches cross the subaponeurotic space to the underlying bones. Scalping does not cause necrosis of the bones of the vault, most of whose blood comes from the middle meningeal artery.

The **occipital artery** emerges from the apex of the

posterior triangle and runs with the greater occipital nerve to supply the back of the scalp up to the vertex. The *posterior auricular artery* runs with the lesser occipital nerve to supply the scalp behind the ear.

The **superficial temporal artery** is a terminal branch of the external carotid. Running up behind the temporomandibular joint it crosses the posterior root of the zygomatic arch, where its pulsation can be felt above and in front of the tragus of the ear, and branches out widely into the skin that overlies the temporalis fascia. One branch, the *middle temporal artery*, pierces the fascia and runs up vertically deep to the muscle. Its companion vein produces a vertical groove on the squamous part of the temporal bone.

The **supraorbital** and **supratrochlear arteries** (from the ophthalmic) run with the corresponding nerves. The supraorbital is the larger and supplies the front of the scalp up to the vertex. Its anastomosis with the superficial temporal artery connects the internal and external carotid systems.

The **veins** of the scalp run back with the arteries. In forehead, temple and occipital regions they receive diploic veins from frontal, parietal and occipital bones.

The supraorbital and supratrochlear veins drain by the angular vein into the facial vein. The superficial temporal veins run into the retromandibular vein, and occipital veins reach the plexus around the semispinalis capitis muscle. The posterior auricular vein drains the scalp behind the ear, and receives also the mastoid emissary vein from the sigmoid sinus. Infection here can be dangerous or fatal, from retrograde thrombosis of cerebellar and medullary veins.

Lymph drainage

There are no lymph nodes within the scalp; lymphatic channels drain to nodes outside it — to occipital and posterior auricular nodes behind the ear, and to preauricular and (crossing the face) to submandibular nodes in front of the ear. The lymph eventually reaches the nodes of the deep cervical chain (p. 522).

Nerve supply

The main sensory nerves run with the arteries. Posteriorly the greater occipital and third occipital nerves (posterior rami of C2 and C3 respectively) extend to the vertex and the posterior scalp respectively. The lesser occipital (anterior ramus of C2) supplies skin behind the ear. The temple is supplied by the auriculotemporal and the zygomaticotemporal nerves, and the forehead and front of the scalp by the supratrochlear and supraorbital nerves.

TEMPORAL FOSSA AND ZYGOMATIC ARCH

Examine a skull. There are two *temporal lines*, superior and inferior. They diverge from a common origin at the border of the zygomatic process of the frontal bone, and sweep boldly up in a convexity that takes them back behind the ear. The area of bone between them is polished.

The **temporal fossa** is the area bounded by the temporal lines above and the zygomatic arch below. Its roof is the temporalis fascia and its floor is the part of the side of the skull that includes the important landmark called the pterion (p. 644). The zygomatic bone and the zygomatic processes of the frontal bone and maxilla are in the anterior wall, and the supramastoid crest continues the line of the upper margin of the arch backwards. The fossa is filled by the temporalis muscle which arises from the floor and the overlying fascia. Deep to the arch, at the level of the infratemporal crest of the greater wing of the sphenoid, the fossa becomes continuous with the lateral part of the infratemporal fossa (p. 457).

The **zygomatic arch** is formed by processes of the squamous temporal and zygomatic bones, which meet at a suture sloping downwards and backwards. The arch is completed anteriorly by the zygomatic process of the maxilla (p. 645).

Nerves crossing the arch are vulnerable in incisions or in fractures. The auriculotemporal nerve crosses well back, just in front of the ear, and temporal and zygomatic branches of the facial nerve also cross the arch, to reach frontalis and eyelid muscles.

The **temporalis fascia** is attached to the superior temporal line and passes down to the upper border of the zygomatic arch. It is a rugged membrane; the superficial temporal vessels and auriculotemporal nerve lie upon it, and it is perforated by the middle temporal artery and vein.

Temporalis

This muscle (one of the muscles of mastication — p. 455) arises from the temporal fossa over the whole area between the inferior temporal line and the infratemporal crest. The muscle is small in the newborn and rises up the side of the skull as the individual grows. The most anterior fibres are vertical and the most posterior are *horizontal*, turning downwards over the root of the zygomatic arch. The large fan-shaped muscle converges towards the coronoid process of the mandible, and its muscle fibres become tendinous. The insertion begins at the deepest part of the mandibular notch and climbs over the coronoid process on to the

front of the ramus. Very little of the tendon is inserted beyond the border of the coronoid process into the outer plate of the mandible: the main insertion is into the bevelled surface on the *inner plate of the bone*, at the posterior border of the coronoid process and at the anterior border down the ascending ramus as far as the attachment of the buccinator in the retromolar fossa (Figs 6.14 and 8.14, p. 664).

The blood supply of the muscle is derived from the temporal branches of the maxillary artery, reinforced by the middle temporal artery (p. 459).

Nerve supply. By the two deep temporal branches of the mandibular nerve, sometimes reinforced by a middle temporal nerve.

Action. Its upper and anterior fibres elevate the mandible (close the jaws); its posterior fibres, sweeping over the root of the zygoma, retract the mandible. They are the *only* fibres to do so; no other muscle retracts the condyle.

PART 8 PAROTID REGION

The part of the face below and in front of the ear and below the zygomatic arch is the parotid region. The principal features are the parotid gland and the masseter muscle (one of the mastication group; the others are temporalis, p. 454, and the two pterygoids, p. 457).

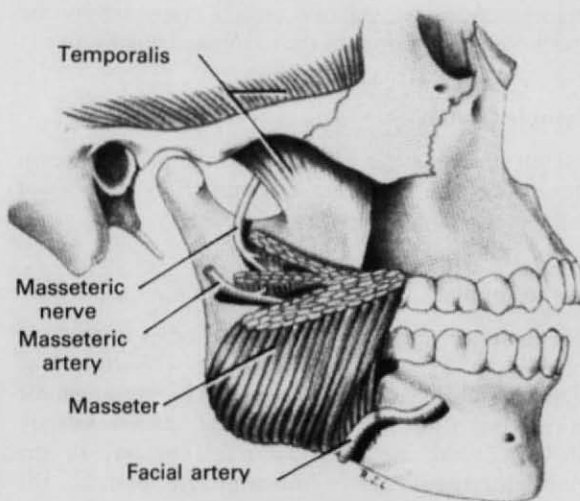


Fig. 6.14 Insertions of the three parts of the right masseter.

Masseter

This muscle arises from the zygomatic arch. Its commonly described two heads are, in fact, three, though they are fused together on the arch (Fig. 6.14). At their insertions on the mandibular ramus the three sets are fused anteriorly, but diverge from each other posteriorly for the passage of the masseteric nerve and artery. The *superficial part* of the muscle is the largest. It arises from the anterior two-thirds of the lower border of the zygomatic arch as far forward as the zygomatic process of the maxilla. Its fibres slope down at 45° and are inserted into a wide area: from the angle of the mandible forwards along the lower border, and upwards to include the lower part of the ramus.

The upper part of the muscle is covered in aponeurotic fibres (to slide on the parotid duct and the accessory parotid gland), the lower half is fleshy. The *intermediate part* of the muscle arises from the middle third of the arch and the *deep part* from the deep surface of the arch in continuity. The fibres pass vertically downwards to be inserted into the ramus of the mandible. Their insertions fuse with each other and with the superficial fibres at the anterior border of the ramus, but are separate posteriorly. The masseteric nerve runs down between the deep and intermediate parts, and a branch from the superficial temporal or transverse facial artery runs forwards between the superficial and intermediate parts. Nerve and artery thus incompletely divide the muscle into three parts (Fig. 6.14). The artery is the chief source of supply to the muscle; the vessel accompanying the masseteric nerve is very small.

Nerve supply. By the masseteric branch from the anterior division of the mandibular nerve (p. 461).

Action. To close the jaws by elevating and drawing forwards the angle of the mandible.

PAROTID GLAND

The **parotid gland** is predominantly a serous salivary gland, with only a few scattered mucous acini. It has an irregular shape because it fills in the gap between the mastoid process, ramus of the mandible and styloid process, spilling over in variable degrees on to the muscles attached to these bones (Figs 6.2 and 6.9). It is best described as having upper and lower poles and three surfaces that are most logically called lateral, anterior and deep. It is surrounded by a tough capsule, the *parotid sheath*, derived from the investing layer of deep cervical fascia. Mumps, a virus infection of the gland, is painful because the gland swells within this tight fibrous envelope.

The *upper pole* is a small concave surface that adheres to the cartilage of the external acoustic meatus and lies adjacent to the capsule of the temporomandibular joint. The *lower pole* is rounded, lying below and behind the angle of the mandible and indented by it and sternocleidomastoid, and overlapping the posterior belly of digastric.

The **lateral surface** is subcutaneous and almost flat. The **anterior surface** (often called anteromedial) is U-shaped, clasping the ramus of the mandible with masseter on its outer surface and the medial pterygoid on its inner surface inferiorly. The stylomandibular ligament separates this surface from the medial pterygoid and from the posterior part of the submandibular gland. The outer edge of this surface meets the lateral surface over masseter to form the convex *anterior border*, deep to which emerge the parotid duct and the five (groups of) branches of the facial nerve that fan out over the face. From the deeper part of this surface the terminal branches of the external carotid artery (superficial temporal and maxillary) leave the gland.

The **deep surface** (often called posteromedial) is the most irregular and complicated. It is indented by the mastoid process and its attached muscles (sternocleidomastoid laterally and the posterior belly of digastric medially), and lies against the styloid process with its three attached muscles (stylohyoid, styloglossus and stylopharyngeus) and two ligaments (stylohyoid and stylomandibular). The external carotid artery enters the gland through the lower part of this surface, which joins the deep edge of the anterior surface. If the gland is large this edge extends forwards in front of the styloid process to approach the superior constrictor of the pharynx. The styloid process separates the gland from the internal jugular vein and (deeper) the internal carotid artery. The temporozygomatic and cervicofacial branches of the facial nerve enter the gland between the styloid and mastoid processes. If the gland is retracted forwards from sternocleidomastoid and the acoustic meatus (as during parotidectomy), a small arrow-like projection of the meatal cartilage conveniently points downwards towards the nerve.

Embedded *within the gland* are the facial nerve, retromandibular vein and external carotid artery, in that order from superficial to deep. Although the facial nerve enters the deep surface it passes forwards to become the most superficial of the embedded structures, as approached from the superficial surface. Note that the branches of the nerve emerge from behind the anterior border, not from the lateral surface. The gland is often described as having superficial and deep parts in relation to the nerve branches, as though during development the nerve had become enclosed in a sandwich

of two layers of parotid tissue, but this is not a correct concept. Immediately deep to the plane of the nerve branches is the retromandibular vein, which can be a guide to the position of the nerves; follow the tributaries of the external jugular vein upwards into the gland, and the nerves will be found immediately superficial to the veins. The external carotid artery and its two terminal branches are the deepest of the large structures within the gland. Lymph nodes of the preauricular group may be within the gland substance as well as just inside the capsule, and the gland is penetrated by filaments of the auriculotemporal nerve which provide the secretomotor fibres.

The **parotid duct** (of Stensen), 5 cm long, passes forwards across the masseter and turns around its anterior border to pierce the buccinator. It lies in the line between the intertragic notch of the auricle and the midpoint of the philtrum and is palpable (feel it on yourself as it passes over the clenched masseter muscle). The duct opens on the mucous membrane of the cheek opposite the second upper molar tooth; it pierces the buccinator further back and runs forwards beneath the mucous membrane to its orifice — the valvular flap of mucous membrane so produced prevents inflation of the gland when intraoral pressure is raised.

An **accessory parotid gland** usually lies on the masseter between the duct and the zygomatic arch. Several ducts open from it into the parotid duct. It and the duct lie on the tendinous part of the surface of the masseter muscle.

Blood supply

Branches from the external carotid artery supply the gland. Venous return is to the retromandibular vein.

Lymph drainage

Lymph drains to the nodes within the parotid sheath and thence with the external carotid artery to nodes of the upper group of deep cervical nodes.

Nerve supply

Secretomotor fibres arise from cell bodies in the otic ganglion (p. 35) and reach the gland by 'hitch-hiking' along the auriculotemporal nerve. The preganglionic fibres arise from cell bodies in the inferior salivary nucleus in the medulla, and travel by way of the glossopharyngeal nerve, its tympanic branch, the tympanic plexus and the lesser petrosal nerve to the otic ganglion. Sympathetic (vasoconstrictor) fibres reach the

gland from the superior cervical ganglion by way of the plexus on the external carotid and middle meningeal arteries. The gland itself receives sensory fibres from the auriculotemporal nerve, but the parotid fascia receives its sensory innervation from the great auricular nerve (C2).

Structure

Histological sections of the parotid gland are characterized by three features that distinguish it from the other main salivary glands: predominantly serous acini, many ducts, and fat cells scattered between the acini and ducts. Compare these features with the submandibular gland, which has a mixture of serous and mucous acini (including mucous acini with serous demilunes at their periphery), and few ducts, and the sublingual gland which has almost exclusively mucous acini and few ducts.

Development

A groove that appears in the cheek (ectoderm) becomes converted into a tunnel from the blind end of which cells proliferate to form the gland.

Surgical approach

Removal of the parotid gland (*parotidectomy*) is an exercise in dissection of the facial nerve. An S-shaped incision is made from in front of the ear, backwards to the mastoid process and then downwards and forwards below the angle of the mandible. The skin incision includes platysma. The gland is retracted forwards from sternocleidomastoid to expose the posterior belly of digastric and stylohyoid and the cartilage of the external meatus. The trunk of the facial nerve is approached along a plane in front of the anterior margin of the cartilage, above stylohyoid and digastric. The stylomastoid branch of the posterior auricular artery is slightly more superficial than the facial nerve and is a guide to its proximity. The cartilage in this region has a slight arrow-headed projection that conveniently points towards the nerve, which can be followed forward from here along its various branches as gland tissue is dissected away. The parotid duct is divided at the anterior border of the masseter. For total as distinct from superficial parotidectomy (which has been described so far), further tissue is dissected away with ligation of the external carotid, superficial temporal and maxillary arteries and adjacent veins. The styloid process may have to be fractured and the stylo-mandibular ligament divided.

PART 9 INFRATEMPORAL REGION

INFRATEMPORAL FOSSA

This is a space lying beneath the base of the skull between the side wall of the pharynx and the ramus of the mandible.

Boundaries

Its *medial boundary* is the lateral surface of the lateral pterygoid plate with, behind it, the tensor and levator palati muscles and the superior constrictor. In front of the lateral pterygoid plate, between it and the maxilla, is the pterygomaxillary fissure through which the infratemporal fossa communicates with the pterygopalatine fossa (p. 466). The *lateral wall* is the ramus of the mandible and its coronoid process. The *anterior wall* is the posterior (infratemporal) surface of the maxilla, which contains small foramina for the posterior superior alveolar nerves and vessels. At the upper margin of this wall of the maxilla there is a gap between it and the greater wing of sphenoid — the inferior orbital fissure. The *roof* of the fossa is formed medially by the infratemporal surface of the greater wing of the sphenoid and the adjacent squamous part of the temporal bone in front of the articular tubercle. This infratemporal surface of the sphenoid is bounded laterally by the infratemporal crest, where the bone takes an almost right-angled turn upwards to become part of the side of the skull, deep to the zygomatic arch and part of the temporal fossa (p. 454). Thus the roof of the infratemporal fossa lateral to the infratemporal crest is not bony, but is the space deep to the zygomatic arch where the temporal and infratemporal fossae communicate. The *posterior boundary* is the upper part of the carotid sheath (p. 462).

Contents

The fossa contains the medial and lateral pterygoid muscles and intervening fat; the insertion of temporalis into the coronoid process; the maxillary artery and branches and the pterygoid venous plexus; the mandibular nerve and its branches together with the otic ganglion and the chorda tympani; and the posterior superior alveolar branches of the maxillary nerve.

Lateral pterygoid

This muscle arises by two heads: the upper from the

infratemporal surface of the skull (see above) and the lower from the lateral surface of the lateral pterygoid plate (Fig. 6.15). The two heads, lying edge to edge, converge and fuse into a short thick tendon that is inserted into the pterygoid fovea (beneath the medial end of the mandibular head). The upper fibres of the tendon, lying above this pit, pass back into the articular disc of the temporomandibular joint, and into the anterior part of the capsule.

Nerve supply. By a branch from the anterior division of the mandibular nerve.

Action. When the muscle contracts it draws condyle and disc forwards from the mandibular fossa down the slope of the articular tubercle (p. 651). It is indispensable to *active* opening of the mouth.

Medial pterygoid

This muscle also arises by two heads. The *deep head* is by far the larger and comes from the medial (deep) surface of the lateral pterygoid plate and the depths of the fossa between the two plates. (Note that the medial pterygoid plate has the pharynx attached to its posterior border and thus forms the posterior part of the lateral wall of the nose, while the lateral pterygoid plate lies sandwiched between the two pterygoid muscles.) The bulky muscle diverges down from the lateral pterygoid muscle at nearly a right angle from their common origin beside the lateral pterygoid plate (Fig. 6.15). A small band of muscle, the *superficial head*, arises from the tuberosity of the maxilla and the pyramidal process of

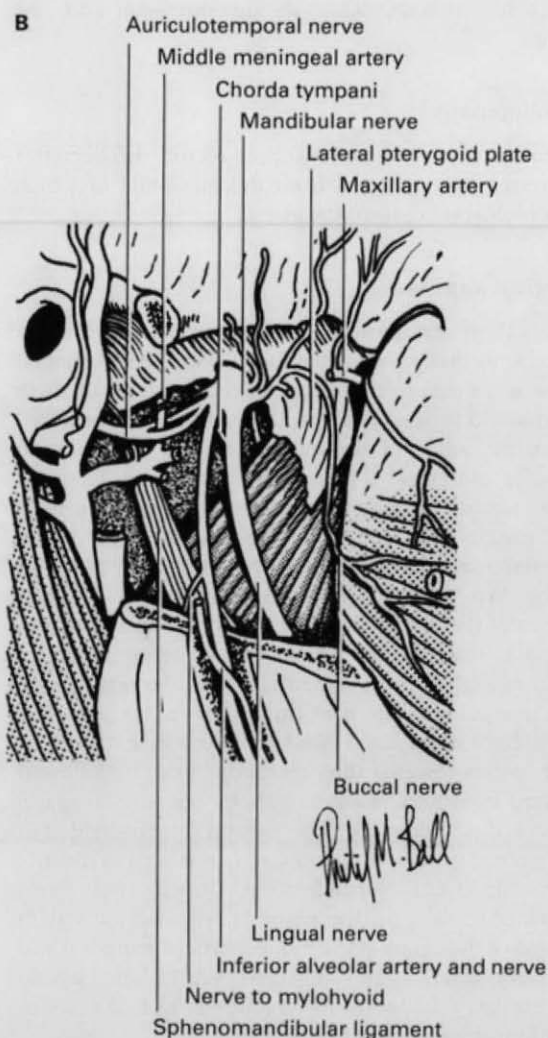
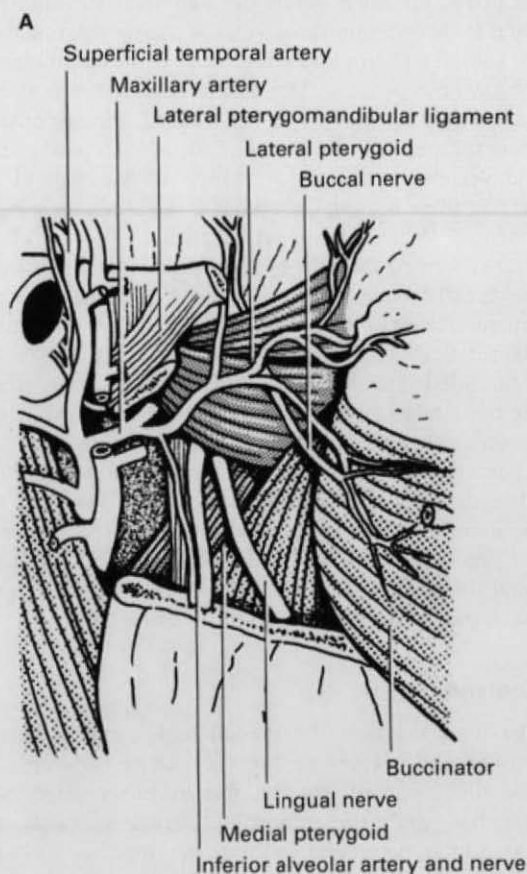


Fig. 6.15 Right infratemporal region. **A** With the two pterygoid muscles in situ. **B** After removal of the lateral pterygoid.

the palatine bone and, passing over the lower margin of the lateral pterygoid muscle, fuses with the main muscle mass. In this way the two heads, very unequal in size, embrace the lower edge of the lateral pterygoid. The broad band of muscle passes down and back at 45° (and *laterally*) to reach the angle of the mandible. It is inserted from the border of the angle over the rough area seen on the bone as far as the groove for the mylohyoid vessels and nerve. The nerve runs in the narrow angle between the muscle and the mandible (Figs 6.15 and 8.14, p. 664).

Nerve supply. By a branch from the main trunk of the mandibular nerve.

Action. The pull of the muscle on the angle of the mandible is upwards and forwards and *medially* (i.e. it closes the mouth and moves the mandible towards the opposite side). It is the great chewing muscle for the molar teeth and is particularly developed in the chewing mammals, especially the ruminants, which chew and re-chew the cud (p. 524). Contracting with its opposite fellow and the two lateral pterygoids, it helps to protrude the mandible.

Maxillary artery

The **maxillary artery** is, with the superficial temporal artery, a terminal division of the external carotid. It enters the infratemporal fossa by winding around deep to the neck of the mandible and passing forwards between the neck of the mandible and the sphenomandibular ligament. Here the auriculotemporal nerve lies above it, and the maxillary veins below it. It usually runs deep to the lower head and passes forward between the two heads of the lateral pterygoid muscle (Fig. 6.15) but, like vascular patterns elsewhere, variation is common and the artery may pass below (or, more rarely, above) the muscle. In any case it passes deeply into the pterygomaxillary fissure and so into the pterygopalatine fossa.

It is described conventionally in three parts, before, on and beyond the lateral pterygoid muscle and this is useful, since *five branches come from each part*. From first and third parts the five branches all enter foramina in bones, from the second part none go through foramina in bones.

The five ('bony') branches from the **first part** are the inferior alveolar, middle meningeal, accessory meningeal and, to complete the five, two branches to the ear. The first two are the most important; in dissections note that they arise very near one another and pass respectively straight down and straight up.

The **inferior alveolar artery** passes downwards and forwards (vein behind it) towards the inferior

alveolar nerve, which it meets at the mandibular foramen, in which all three lie. It passes forwards in the mandible, supplying the pulps of the mandibular teeth (*dental branches*) and the body of the mandible. Its *mental branch* emerges from the mental foramen and supplies the nearby lip and skin. In the edentulous mandible of old age where alveolar bone has become resorbed the artery atrophies.

The **middle meningeal artery** passes vertically upwards to the foramen spinosum. It is embraced by the two roots of the auriculotemporal nerve. It supplies bone of the skull (p. 562). From the sympathetic plexus on the artery a branch peels off to enter the otic ganglion.

The **accessory meningeal artery** passes upwards through the foramen ovale and supplies the dura mater of the floor of the middle fossa and of the trigeminal (Meckel's) cave. It is the chief source of blood supply to the trigeminal ganglion.

The remaining two arteries pass upwards to enter the ear by running superficial and deep to the tympanic membrane. The **deep auricular artery** is the more superficial of the two and supplies the external acoustic meatus, passing between the cartilage and bone. The deeper is the **anterior tympanic artery** which passes through the petrotympanic fissure to the middle ear to join the circular anastomosis around the tympanic membrane.

The **second part** of the maxillary artery gives off branches to the pterygoid muscles and *deep temporal* branches to temporalis. Further branches accompany the lingual and buccal nerves. Together they can be summarized as five in number to the soft parts.

The **third part** of the maxillary artery, in the pterygopalatine fossa, gives five branches which accompany nerves including branches of the pterygopalatine ganglion (p. 468). The artery then leaves the fossa through the sphenopalatine foramen, changing its name to the sphenopalatine artery and becoming the main artery of the nasal cavity (p. 472).

The **posterior superior alveolar artery** gives branches that accompany the corresponding nerves through foramina in the posterior wall of the maxilla. The **greater palatine artery** enters the foramen of the same name to reach the hard palate (p. 480). The very small **pharyngeal artery** enters the palatovaginal canal, and the **artery of the pterygoid canal** runs into its own canal. The **infraorbital artery** passes forwards through the inferior orbital fissure, along the floor of the orbit and infraorbital canal to emerge with the infraorbital nerve on the face.

The **posterior superior alveolar nerve** is a branch of the maxillary, given off in the pterygopalatine fossa

and soon dividing into two or three *dental branches* which pierce the posterior wall of the maxilla separately; their foramina can usually be seen in the dried skull. They are distributed to the molar teeth and the mucous membrane of the maxillary sinus. Another (*gingival*) branch does not pierce the bone but runs along the alveolar margin of the maxilla as far forward as the first molar tooth, to supply the gingiva of the vestibule alongside the molar teeth. (The adjacent mucous membrane of the cheek that lines the buccinator is supplied by the buccal branch of the mandibular nerve.) The mucous membrane of the vestibule of the mouth is reflected at the lateral part of the anterior wall of the infratemporal fossa and the posterior superior alveolar nerves can be blocked by injection here. Around the tip of the injecting needle lie the vessels mentioned above and the pterygoid venous plexus (see below). They can be punctured, with a consequent haematoma of some size.

The **pterygoid plexus** is a network of very small veins that lie around and *within* the lateral pterygoid muscle. It is frequently not demonstrable in the dissected cadaver (because it lies *within* the muscle); sometimes it appears as a knot of veins on the lateral surface of the lower head of the muscle. In the living it is often very full, and can easily be punctured by the needle delivering an anaesthetic solution in the region of the posterior superior alveolar nerves. The veins draining into the pterygoid plexus correspond with the branches of the maxillary artery, but they do not return all the arterial blood, much of which returns from the periphery of the area by other routes (facial veins, pharyngeal veins, diploic veins). On the other hand the pterygoid plexus receives the drainage of the *inferior ophthalmic veins* (p. 514) via the inferior orbital fissure (blood from the *internal carotid artery*) and the *deep facial vein* (p. 452). The pterygoid plexus drains into a pair of large, but very short, **maxillary veins** which lie deep to the neck of the mandible. They run back and join the superficial temporal vein to form the retro-mandibular vein. The deep facial vein provides an alternative pathway, via the facial vein, for drainage of the pterygoid plexus if the maxillary vein is temporarily occluded by local pressures from outside or from the mandible in certain movements, or in the reverse way for drainage of the angular vein if the lower part of the facial vein is occluded by pressure.

The role of the pterygoid plexus is to act as a 'peripheral heart', aiding venous return by the pumping action of the lateral pterygoid muscle. The plexus is valved and sucks blood from incompressible parts (face bones, orbit) and pumps it back into the maxillary veins. It pumps each time the mouth is actively opened (talking

or chewing or both) but not when the mandible droops by gravity (e.g. in sleep). The prolonged and forcible contraction of the lateral pterygoid muscle to open the mouth in yawning is accompanied by a like contraction of the diaphragm to aid venous return from the abdomen, and often also by 'stretching' of the limbs to empty them of stagnant venous blood. Observe a cat or a human awakening from a sleep so deep that the muscles have been very relaxed. Thus it is possible that, at least in some instances, yawning is a purposive reflex triggered off by venous stagnation, but the phenomenon has not been fully explained.

The **sphenomandibular ligament** is a flat band of tough fibrous tissue extending from a narrow attachment on the spine of the sphenoid. It broadens as it passes downwards to be attached to the lingula and inferior margin of the mandibular foramen. It is the perichondrium of Meckel's cartilage (Fig. 1.30, p. 38). Between it and the neck of the mandible pass the auriculotemporal nerve and the maxillary artery and vein. Between it and the ramus of the mandible the inferior alveolar vessels and nerve converge to the mandibular foramen. It is pierced by the **mylohyoid nerve** which, branching from the inferior alveolar nerve, lies in the groove on the mandible at the margin of attachment of the medial pterygoid muscle (Fig. 8.14, p. 664). The *mylohyoid artery*, a similar branch of the inferior alveolar artery, is very small and accompanies the nerve to anastomose with the submental branch of the facial artery. The small vein accompanying the mylohyoid artery is actually responsible for making the mylohyoid groove on the mandible.

MANDIBULAR NERVE

The mandibular branch from the trigeminal ganglion lies in the dura mater of the middle cranial fossa lateral to the cavernous sinus. With the motor root of the trigeminal nerve it enters the foramen ovale, where the two join and emerge as the **mandibular nerve** (like spinal nerve roots in intervertebral foramina). The nerve lies deep to the upper (infratemporal) head of the lateral pterygoid, on the tensor palati muscle, with the otic ganglion applied to the deep surface of the nerve. This point is 4 cm deep to the articular tubercle through the mandibular notch. After a short course the nerve divides into a small anterior (mainly motor) and a large posterior (mainly sensory) branch.

Branches from the main trunk

One sensory and one motor: The **meningeal branch**

or *nervus spinosus*, re-enters the middle cranial fossa via the foramen spinosum, or more usually the foramen ovale, supplying the meninges of the posterior half of the middle cranial fossa, and the mastoid antrum and air cells through the petrosquamous suture. It gives twigs to the cartilaginous part of the auditory tube before entering the skull.

The **nerve to the medial pterygoid** runs forwards to the muscle, and gives off the motor root to the otic ganglion (see below). This root passes near or through the ganglion without synapse and its fibres supply the two tensor muscles, tensor palati and tensor tympani. Do not confuse this misnamed motor root with the *secretomotor* root of the ganglion, which is the lesser petrosal nerve (p. 35).

Branches from the anterior division

This division is motor, except for one branch (the buccal nerve).

Deep temporal branches to temporalis pass above the upper border of the lateral pterygoid muscle. Two in number, *anterior* and *posterior*, they are sometimes joined by a third, the *middle*, which comes out, with the buccal nerve, between the two heads of the lateral pterygoid. The nerves run up into the temporal fossa deep to temporalis.

The **masseteric nerve**, passing above the upper border of the lateral pterygoid, emerges through the mandibular notch to enter the deep surface of the masseter (Fig. 6.14). It gives an articular branch to the temporomandibular joint (Hilton's law).

The **nerve to the lateral pterygoid** runs with the buccal nerve and supplies both heads of the muscle.

The **buccal nerve**, wholly sensory, contains all the fibres of common sensation in the anterior division of the mandibular nerve. It emerges between the two heads of the lateral pterygoid (Fig. 6.15) and courses downwards and forwards in a fascial tunnel on the deep surface of temporalis. It runs on the buccinator, giving branches to the skin over the cheek, then pierces the buccinator (giving proprioceptive fibres to it) and supplies the mucous membrane of the cheek and the gum of the lower jaw opposite the lower molars and second premolar (i.e. up to the mental foramen).

Branches from the posterior division

This division is sensory except for the motor fibres which are distributed via the mylohyoid nerve. There are three branches.

The **auriculotemporal nerve** is derived by two roots from the posterior division; they embrace the

middle meningeal artery. The nerve passes backwards between the neck of the mandible and the sphenomandibular ligament, lying above the maxillary vessels, deep to the parotid gland. It gives a branch to the temporomandibular joint, and ascends over the posterior root of the zygomatic arch behind the superficial temporal vessels (Fig. 6.9). The *auricular* part innervates the skin of the tragus and upper part of the pinna, the external acoustic meatus and the outer surface of the tympanic membrane. The *temporal* part is distributed to the skin of the temple over that part which first turns grey (this area is really skin borrowed from the beard, pulled up towards the vertex as the skull enlarges to accommodate the brain; its former site over the angle of the jaw is replaced by the great auricular — C2). The auriculotemporal nerve also supplies the parotid gland, and carries to it the postganglionic secretomotor fibres from the otic ganglion (Fig. 1.25, p. 34). Note that the nerve does not supply the parotid fascia, whose deep and superficial laminae are supplied by the great auricular nerve.

The **inferior alveolar nerve** emerges below the lower head of the lateral pterygoid and curves down on the medial pterygoid (Fig. 6.15). The nerve lies anterior to its vessels between the sphenomandibular ligament and the ramus of the mandible, and enters the mandibular foramen. It is into this region, just above the foramen, that anaesthetic solution is introduced for inferior alveolar nerve block (p. 478). The *mylohyoid nerve* leaves the inferior alveolar at the foramen. It pierces the sphenomandibular ligament, lies on the mandible above the insertion of the medial pterygoid (Fig. 6.26A) and runs forward on the superficial (cervical) surface of the mylohyoid, supplying it and the anterior belly of the digastric.

The inferior alveolar nerve runs with its vessels in the mandibular canal. It supplies the three molar and two premolar teeth. Then it divides into the *mental nerve* (p. 452) and the *incisive nerve*. This nerve supplies the pulps and periodontal membranes of the canine and both incisors, with some overlap into the opposite central incisor.

The **lingual nerve** appears below the lateral pterygoid on the side wall of the pharynx and passes forwards and downwards between the medial pterygoid and the mandible (Fig. 6.15). It then comes into contact with the mandible, sometimes leaving a groove below and medial to the third molar, just above the posterior end of the mylohyoid line (Fig. 6.26). This groove separates the attachments of the pterygomandibular raphe above and mylohyoid muscle below (Fig. 8.14, p. 664). The nerve thus enters the mouth on the surface of the mylohyoid, beneath the mucous membrane of the floor of the

mouth. The **chorda tympani** (from the facial nerve, p. 530) emerges through the petrotympanic fissure, grooves the spine of the sphenoid, and joins the lingual nerve 2 cm below the base of the skull and is distributed with it to the anterior two-thirds of the tongue. It carries all the parasympathetic secretomotor fibres to the submandibular ganglion and all the taste fibres from the anterior two-thirds of the tongue (p. 483).

Otic ganglion

This small body lies between the tensor palati and the mandibular nerve, just below the foramen ovale. It is about 2–3 mm in diameter and is not a round pea-like structure as often depicted in drawings, but flat and closely applied to the nerve. It is a relay station for parasympathetic secretomotor fibres to the parotid gland; the lesser petrosal branch of the glossopharyngeal nerve brings these fibres. A branch from the nerve to the medial pterygoid passes through the ganglion to the tensor muscles (tympani and palati). The connexions of the otic ganglion are given on page 34 (Fig. 1.25).

CAROTID SHEATH AND CRANIAL NERVES

In contact with the prevertebral fascia the carotid sheath lies on the side wall of the pharynx. Lateral to it the three muscles of the styloid apparatus slope down.

Carotid sheath

The **carotid sheath** extends from the arch of the aorta to the base of the skull (p. 650). In its upper part it is attached to the margins of the carotid canal in the petrous bone and to the inferior border of the tympanic part of the temporal bone where it blends with the deep layer of the parotid fascia (p. 423). It contains here the internal carotid artery and internal jugular vein (p. 438) and the last four (ninth to twelfth) cranial nerves. Medial to it lies the pharynx; laterally the deepest part of the parotid gland touches the sheath and above this the styloid process and its three muscles slope downwards and forwards. Anteriorly is the infratemporal fossa, of which the carotid sheath may be said to form the posterior boundary. Behind the carotid sheath lies the cervical sympathetic trunk on the prevertebral fascia.

Examine a skull. The *carotid canal* lies immediately in front of the *jugular foramen* (which lies deep to the external acoustic meatus) with the hypoglossal canal more medially between them. The internal jugular vein lies behind the internal carotid artery at the base of the skull, but slopes as it descends, and at a lower level lies

lateral to the common carotid artery as the vessels lie on scalenus anterior. At all levels the *vagus nerve* lies deep in the groove between the two, bound in the carotid sheath. The glossopharyngeal and accessory nerves emerge at the base of the skull between artery and vein and immediately curve away from each other superficial to the vessels (Fig. 6.16). The *hypoglossal nerve* emerges from the hypoglossal canal medial to the sheath. It passes through the sheath by curling down behind the inferior vagal ganglion and turning forwards to emerge between the artery and vein. Throughout its course to the tongue it has arteries deep and veins superficial to it.

While the internal carotid artery enters the skull (hence its name), the external carotid does not reach the base of the skull, having divided into its terminal branches within the parotid gland. To help sort out the relationships below the skull of these vessels (and the internal jugular vein) with the last four cranial nerves, study Figure 6.16 while noting the following. The common carotid artery divides like a two-pronged fork. Passing between the prongs, i.e. between the internal and external carotids, are: the styloid process and its continuation the stylohyoid ligament, styloglossus, stylopharyngeus, the glossopharyngeal nerve with its branch to stylopharyngeus and its pharyngeal branch, and the pharyngeal branch of the vagus (and also if present the track of a branchial fistula). Stylohyoid (with the posterior belly of digastric, not shown in this figure) passes superficial to the external carotid, and so at a lower level does the hypoglossal nerve. Passing deep to both carotids is the superior laryngeal nerve and its two branches, the internal and external laryngeals. It is perhaps an aid to memory to say that pharyngeal structures (with an 'f' sound) pass through the carotid fork — stylopharyngeus, the glossopharyngeal nerve, the pharyngeal branches of it and the vagus, and the branchial fistula track.

Glossopharyngeal nerve

The **glossopharyngeal nerve**, the nerve of the third pharyngeal arch (p. 38), emerges from the anterior part of the jugular foramen on the lateral side of the inferior petrosal sinus (p. 567). It makes a deep notch in the inferior border of the petrous bone and here its *inferior ganglion* bulges the nerve. (The smaller superior ganglion is simply the detached upper part of the inferior.) The ganglion contains the cell bodies of most sensory fibres in the nerve. The nerve passes down on the internal carotid artery and curves forward around the lateral side of stylopharyngeus (Fig. 6.30). Passing now parallel with the lower border of styloglossus, below the lower border of the superior constrictor

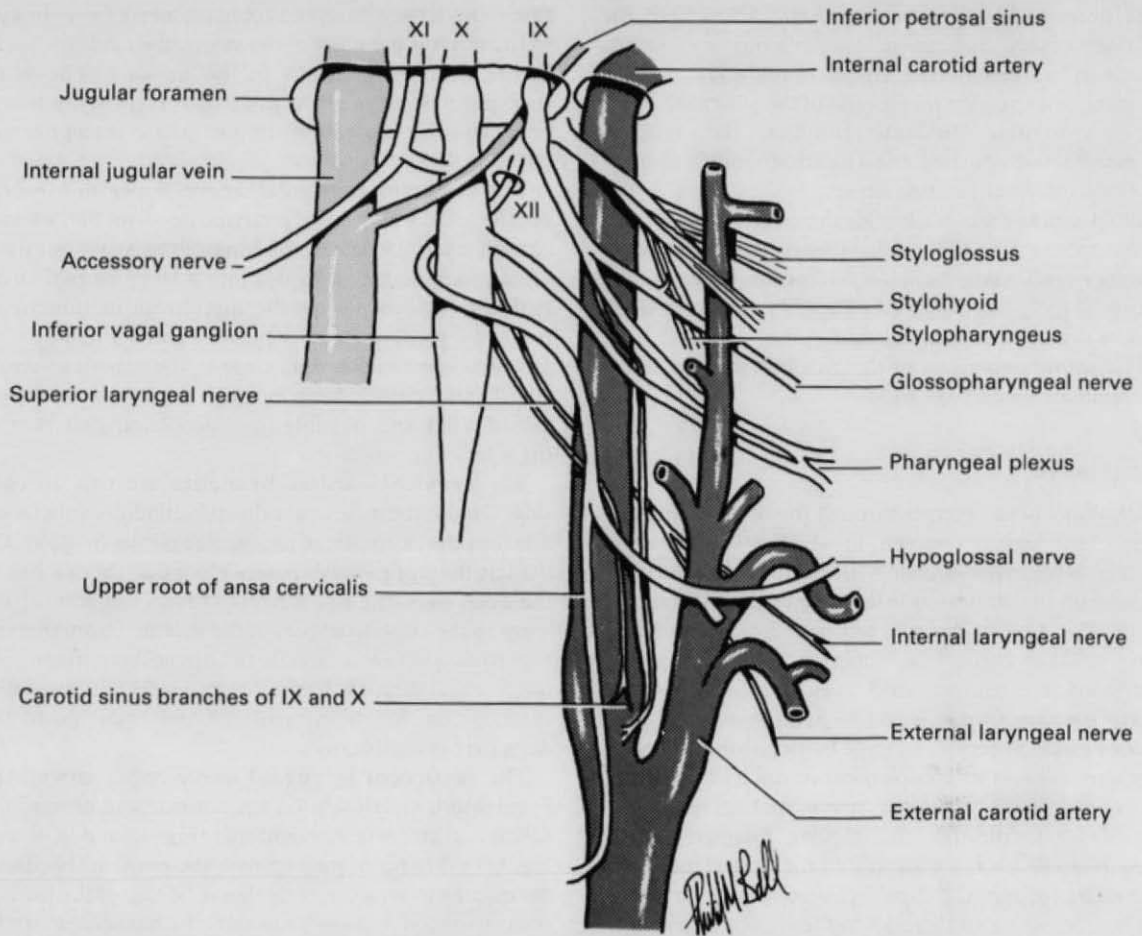


Fig. 6.16 Exploded diagram of great vessels and adjacent nerves in the upper part of the neck and below the skull. The superior laryngeal nerve (from the vagus) and its internal and external laryngeal branches are the deepest structures shown, and the hypoglossal nerve becomes the most superficial. See text for further details.

muscle, it passes high up behind the posterior border of the hyoglossus and so reaches the tongue (p. 483).

Its six branches are as follows:

The **tympanic branch** (Jacobson's nerve) leaves the nerve at the inferior ganglion and passes through the tympanic canaliculus on the ridge of petrous bone between the carotid and jugular foramina to supply the middle ear, mastoid air cells and bony part of the auditory tube with sensory fibres. In this branch are also parasympathetic fibres from the inferior salivary nucleus. They run through the tympanic plexus on the promontory, leave the middle ear in the lesser petrosal nerve (p. 530) and so pass to relay in the otic ganglion (Fig. 6.18) for the secretomotor supply of the parotid gland and the other small glands of the vestibule of the mouth.

The **motor branch** to stylopharyngeus is given off as the nerve spirals around the posterior border of that muscle. The cell bodies of the motor axons lie in the nucleus ambiguus.

The **carotid sinus nerve** is the main supply to the carotid sinus and carotid body (baroreceptors and chemoreceptors, p. 438). This small nerve, rarely displayed in the average dissected specimen, is of great importance in view of its connexions via the nucleus of the tractus solitarius (p. 610) with the vasomotor and other autonomic centres in the reticular formation of the brainstem.

One or more **pharyngeal branches** join the pharyngeal plexus on the middle constrictor muscle. They pierce the muscle and supply the mucous membrane of the oropharynx with common sensation and (a few)

taste fibres and with parasympathetic fibres from the inferior salivary nucleus to the mucous and serous glands of the oropharynx (these fibres relay in small ganglia in the mucous membrane of the pharynx).

The **tonsillar branch** supplies the mucous membrane over part of the (palatine) tonsil, anastomosing with lesser palatine nerves.

The **lingual branch** supplies the posterior one-third of the tongue (p. 483) with sensory fibres (common sensation and taste) and secretomotor fibres to the glands of the posterior third. These last relay in small ganglia in the mucous membrane.

The *central connexions* of the glossopharyngeal nerve are summarized on page 615.

Vagus nerve

The **vagus nerve** emerges through the middle compartment of the jugular foramen, in which a small enlargement constitutes the *superior ganglion*. Just below the base of the skull the elongated **inferior ganglion** dilates the trunk. The ganglia contain cell bodies of the afferent fibres of the vagus; the superior ganglion for the unimportant meningeal and auricular branches, the *inferior ganglion for all the sensory fibres that matter*. The inferior ganglion receives a large branch from the accessory nerve; this is its complement of nucleus ambiguus fibres, which the accessory nerve (cranial part) has carried for it through the jugular foramen. These nucleus ambiguus fibres supply all the *striated* muscle of the viscera (pharynx, soft palate, oesophagus, larynx).

The nerve runs straight down the neck, contained in the back of the carotid sheath, between carotid artery and jugular vein. In the root of the neck it passes in front of the subclavian artery and so enters the mediastinum (p. 261) to supply thoracic and abdominal viscera.

Its branches in the neck are as follows:

Meningeal branches pass up from the superior ganglion to supply the dura mater of the posterior fossa below the tentorium.

The **auricular branch** runs laterally between the tympanic and mastoid parts of the temporal bone. It supplies the postero-inferior quadrant of the outer surface of the tympanic membrane and a small adjacent area of skin of the external acoustic meatus and a little of the corresponding skin behind the auricle.

The very fine **carotid body branch** forms a plexus with the carotid sinus branch of the glossopharyngeal for the supply of those structures (above, and p. 438).

The **pharyngeal branch** of the vagus slopes forward across the internal carotid artery parallel with and below the glossopharyngeal nerve and joins the pharyngeal plexus on the middle constrictor muscle (p. 489). Its

fibres are derived from the accessory nerve by its branch to the inferior ganglion of the vagus; their cell bodies lie in the nucleus ambiguus in the medulla. The fibres supply the muscles of the pharynx (except stylopharyngeus) and the muscles of the soft palate (except tensor palati, p. 495).

The **superior laryngeal nerve** slopes downwards on the side wall of the pharynx deep to the internal carotid artery. At about the level of the hyoid bone but often much higher it divides into a large *internal laryngeal nerve* which pierces the thyrohyoid membrane to reach the piriform recess (p. 491) and a small *external laryngeal nerve* which runs close to the superior thyroid vessels and passes down outside the larynx to supply cricothyroid and possibly the cricopharyngeus part of the inferior constrictor.

The **cervical cardiac branches** are two on each side. On the right they pass down behind the subclavian artery to the deep part of the cardiac plexus (p. 259). On the left the upper nerve passes alongside the trachea to the deep part; the lower nerve crosses the arch of the aorta to the superficial part of the plexus. (Note that the superficial part receives only the upper sympathetic and lower vagal branch from the left side; all the other cardiac branches of sympathetic and vagus go to the deep part of the plexus.)

The **recurrent laryngeal nerve** hooks around the ligamentum arteriosum on the left side and around the subclavian artery on the right side (Fig. 4.15, p. 258, and Fig. 6.7). Thence it runs up near the posterior border of the trachea to pass under the lower border of the inferior constrictor (cricopharyngeus part). Its relationship to the thyroid gland is described on page 431. The nerve has cardiac branches, and also supplies the trachea, oesophagus and possibly the cricopharyngeus part of the inferior constrictor before entering the pharynx and larynx to supply the laryngeal muscles (except cricothyroid) and the laryngeal mucosa below the vocal folds (p. 504).

The *central connexions* of the vagus nerve are summarized on page 615.

Accessory nerve

The **accessory nerve** is formed in the posterior cranial fossa by union of *cranial* and *spinal* (cervical) roots. The nerve occupies the middle compartment in the jugular foramen, just lateral to the vagus. All the fibres of its cranial root leave the nerve in a branch which joins the vagus. The nerve, now consisting of cervical fibres only, slopes down on the internal jugular vein where the latter lies on the lateral mass of the atlas. It passes deep to the styloid process and posterior belly of the digastric and gives off a branch to sternocleidomastoid. It pierces

the muscle near the entrance of the motor branch; here it is crossed by the upper sternocleidomastoid branch of the occipital artery. The nerve passes through the muscle across the posterior triangle to trapezius (p. 426), which it supplies. Proprioceptive fibres from the muscles reach the spinal cord in the ordinary way, through C2 and 3 for sternocleidomastoid and through C3 and 4 for trapezius.

Hypoglossal nerve

The **hypoglossal nerve** emerges from the hypoglossal canal. It picks up a *substantial branch from the anterior ramus of C1* and then spirals behind the inferior ganglion of the vagus to emerge between the internal carotid artery and internal jugular vein. It lies on the carotid sheath deep to the styloid muscles and the posterior belly of digastric, then curls forward just beneath the tendon of digastric, across the arteries and deep to the veins (p. 462) to pass to the tongue (p. 482).

All the non-lingual branches of the hypoglossal nerve are formed by hitch-hiking C1 fibres: the small *meningeal branch* which enters the posterior fossa through the hypoglossal canal, the branch to the ansa cervicalis and the branches to thyrohyoid and geniohyoid. The true

hypoglossal fibres supply only tongue muscles. Their cell bodies are in the hypoglossal nucleus in the medulla. The tongue muscle is derived from suboccipital myotomes, which in their migration through the neck pass between the carotid arteries (external and internal) lying deep, and the jugular vein lying superficial, dragging their nerve behind them. There are no sensory fibres in the hypoglossal nerve. In this the nerve resembles the third, fourth, sixth and accessory nerves. The muscles of the orbit and face have a proprioceptive supply (by the trigeminal to its mesencephalic nucleus) and sternocleidomastoid and trapezius, supplied by the spinal part of the accessory, have a proprioceptive supply from C2, 3 and 4. The muscles of the tongue have been shown to contain spindles, but their afferent innervation remains uncertain. It may be via the lingual branch of the mandibular nerve or cervical nerves.

STYLOID APPARATUS

The **styloid process** is a part of the temporal bone that (like the petrous part) ossifies in cartilage. From its tip the *stylohyoid ligament* passes to the lesser horn of the hyoid bone (Fig. 6.17). Both process and ligament are

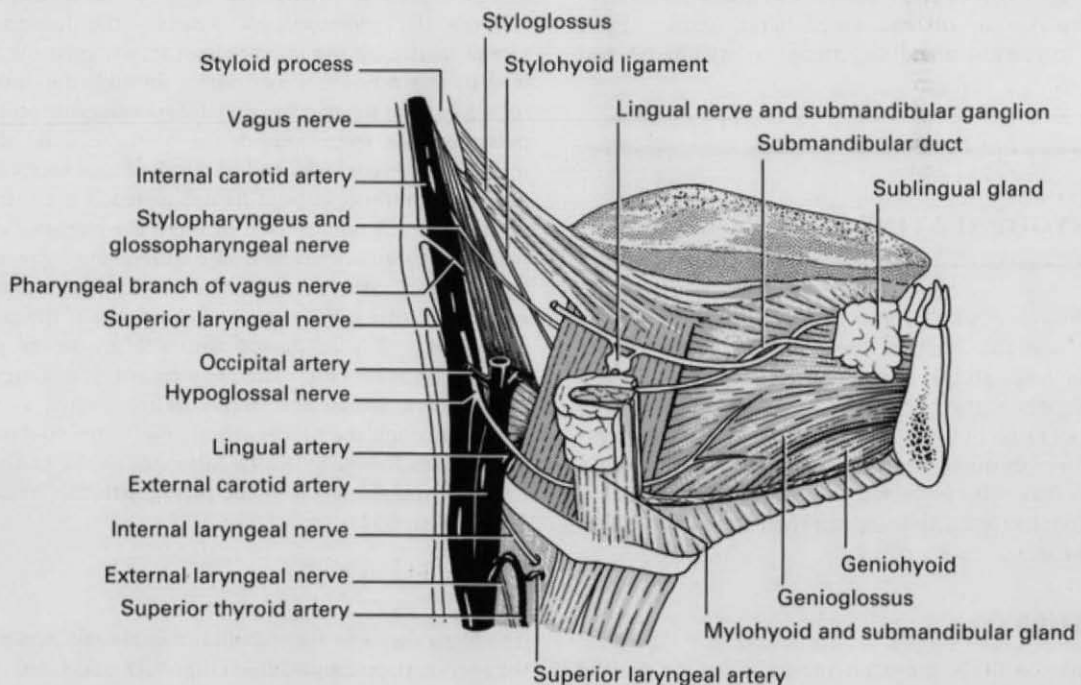


Fig. 6.17 Right styloid process and submandibular region. The right half of the mandible and part of the submandibular and sublingual glands have been removed. The glossopharyngeal nerve, stylohyoid ligament and lingual artery pass deep to the posterior border of hyoglossus; the lingual nerve, submandibular duct and hypoglossal nerve are superficial to hyoglossus.

remnants of the second pharyngeal arch cartilage (p. 38); the unossified cartilage disappears, its perichondrium persisting as the ligament. Hence the styloid process is very variable in length, the ligament varying likewise, inversely with it.

Three muscles diverge from the styloid process and are described where noted. The **stylopharyngeus** (p. 489) is deepest and arises highest; it passes almost vertically downwards to the larynx. The **stylohyoid** (p. 428) arises from behind high up and the **styloglossus** (p. 482) from in front low down; they diverge to the lower and upper borders of the side of the tongue. Each of the three muscles has a different nerve supply. They all act significantly during swallowing (p. 525). The styloid apparatus lies lateral to the carotid sheath and helps the latter to close in the infratemporal fossa posteriorly. Its upper part lies in the bed of the parotid gland.

The **stylomandibular ligament** is a thickening in the deep lamina of the parotid fascia (p. 422). It extends from the vaginal process of the tympanic part of the temporal bone to the angle of the mandible.

The **external carotid artery** passes between the muscles of the stylohyoid apparatus. It runs up deep to digastric and stylohyoid, but superficial to stylopharyngeus (Fig. 6.16), to enter the parotid gland. The retro-mandibular vein on the other hand, passes down from the parotid gland superficial to stylohyoid and digastric.

PART 10

PTERYGOPALATINE FOSSA

This fossa is a small space between the back of the *maxilla* and the front of the *pterygoid process* of the *sphenoid bone*, and is concerned with the blood and nerve supply of the upper jaw. It cannot all be seen in the intact skull, but it communicates with the infratemporal fossa through the *pterygomaxillary fissure*; hold a skull so that you can look into this fissure from below the zygomatic arch, and you can then appreciate where the fossa is.

Boundaries

Examine a skull. In the infratemporal fossa the maxilla and the lower part of the lateral pterygoid plate are joined by the pyramidal process of the palatine bone (Fig. 6.11); they separate above at the pterygomaxillary fissure which leads into the pterygopalatine fossa. On

the lateral wall of the nose the maxilla is separated from the medial pterygoid plate by the perpendicular plate of the palatine bone. This plate articulates with the maxilla; between the two lies the greater palatine canal which opens below at a foramen on the hard palate. The greater palatine canal opens above into the fossa, for here the perpendicular plate of the palatine bone bifurcates; one limb remains attached to the maxilla, the other limb passes back to articulate with the sphenoid (Fig. 8.12, p. 661). Between the two lies the sphenopalatine foramen, leading from the fossa into the lateral wall of the nose (Fig. 6.22B).

The pterygopalatine fossa is thus seen to be bounded *posteriorly* by the sphenoid bone (root of the pterygoid process containing the pterygoid canal and greater wing containing the foramen rotundum, Fig. 8.7, p. 657). *Medially* the fossa is walled in by the palatine bone (with its notch, bounding the sphenopalatine foramen) and *anteriorly* by the posterior wall of the maxilla, below the apex of the floor of the orbit (p. 506). The *roof* is the body of the sphenoid and the orbital process of the palatine.

The passages leading from the fossa should be identified on the skull with the aid of a piece of flexible fine wire or bristle. A wire passed into the *pterygomaxillary fissure* passes across the fossa to enter the nose through the *sphenopalatine foramen*, the last-named closed in life by the mucous membrane of the lateral wall of the nose. A wire passed through the *foramen rotundum* from the middle cranial fossa enters the pterygopalatine fossa from behind; this is the course of the maxillary nerve which, on leaving the fossa, turns *laterally* in the inferior orbital fissure to reach the infra-orbital groove. A wire passed through the *pterygoid canal* from the foramen lacerum also enters the fossa from behind but below and medial to the foramen rotundum; this is the course of the nerve of the pterygoid canal. A wire passed into the *greater or lesser palatine foramina* enters the fossa from below along the canal which lodges the nerves of the palate. A wire passed through the *palatovaginal canal* in the roof of the nose passes forward into the fossa; this is the course of the pharyngeal branch of the pterygopalatine ganglion (Fig. 8.5, p. 651).

Contents

The fossa contains the maxillary vessels and nerve and the pterygopalatine ganglion (Figs 6.18 and 6.19). The ganglion sends branches into the nose and palate, and the maxillary nerve supplies the upper teeth, floor of the orbit and skin of the face. Branches of the maxillary vessels accompany all these nerves.

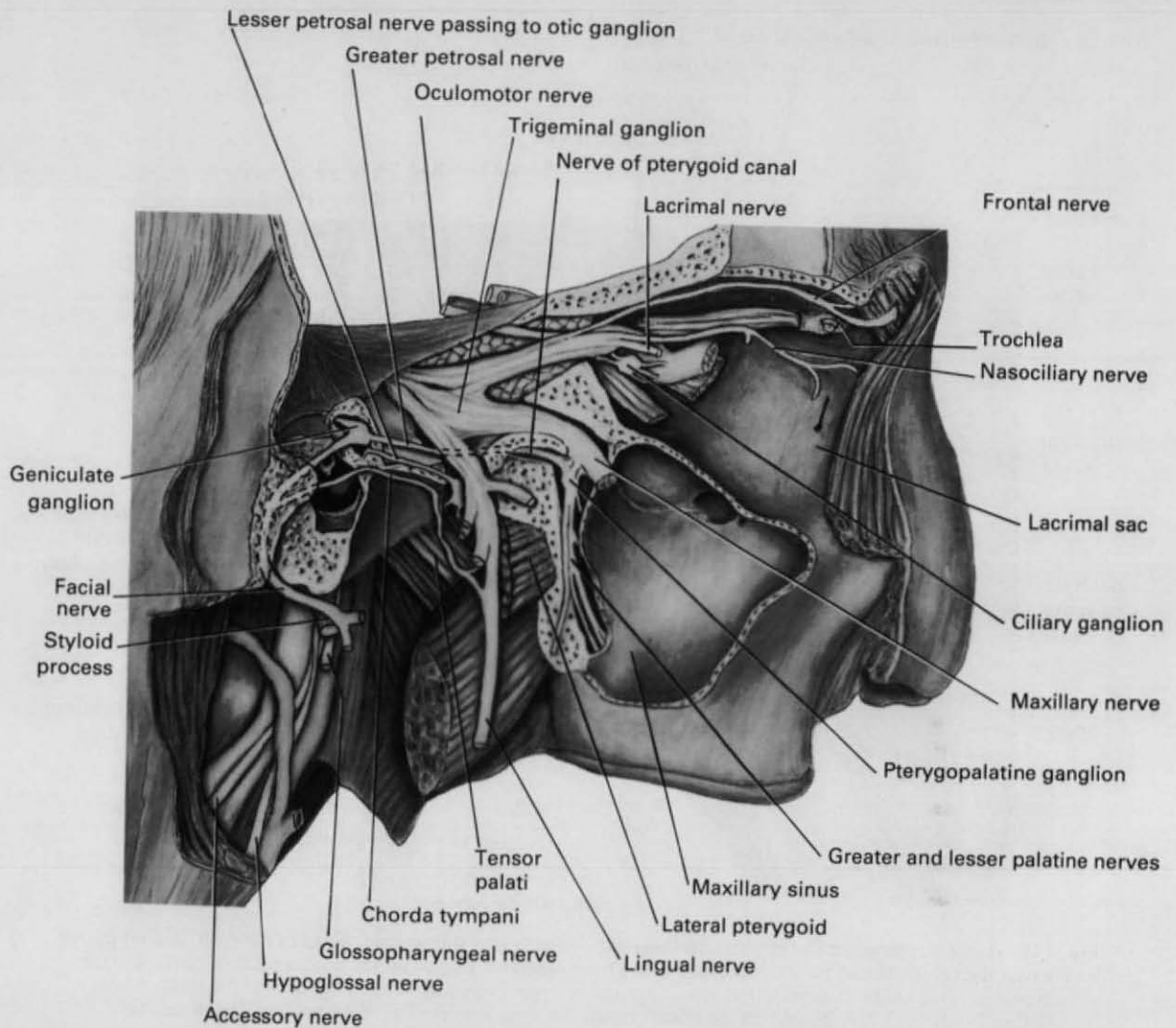


Fig. 6.18 Right trigeminal and geniculate ganglia, petrosal nerves and pterygopalatine and otic ganglia, from the right. Much of the right side of the skull has been removed, including most of the maxillary sinus, leaving only its medial wall.

Maxillary nerve

The **maxillary nerve**, giving a meningeal branch to the front of the middle cranial fossa, passes through the foramen rotundum in the greater wing of the sphenoid bone into the pterygopalatine fossa. Deviating laterally in the inferior orbital fissure for about 1 cm, it turns forwards to enter the infraorbital groove and canal in the floor of the orbit, changing its name to the **infraorbital nerve** and eventually emerging from the front end of the canal at the infraorbital foramen to supply skin on the face (p. 451). The **zygomatic nerve** arises from the maxillary in the fossa and runs above the maxillary in the inferior orbital fissure to enter the orbit (p. 512).

In the fossa the pterygopalatine ganglion is connected to the maxillary by a short thick trunk that contains fibres going both to and from the ganglion, and a little further forward the **posterior superior alveolar nerve** is given off. It passes through the pterygomaxillary fissure on to the posterior wall of the maxilla, where it has already been described (p. 459).

Pterygopalatine ganglion

The **pterygopalatine ganglion** (Fig. 6.19) is a relay station between the superior salivary nucleus in the pons and the lacrimal gland and mucous and serous

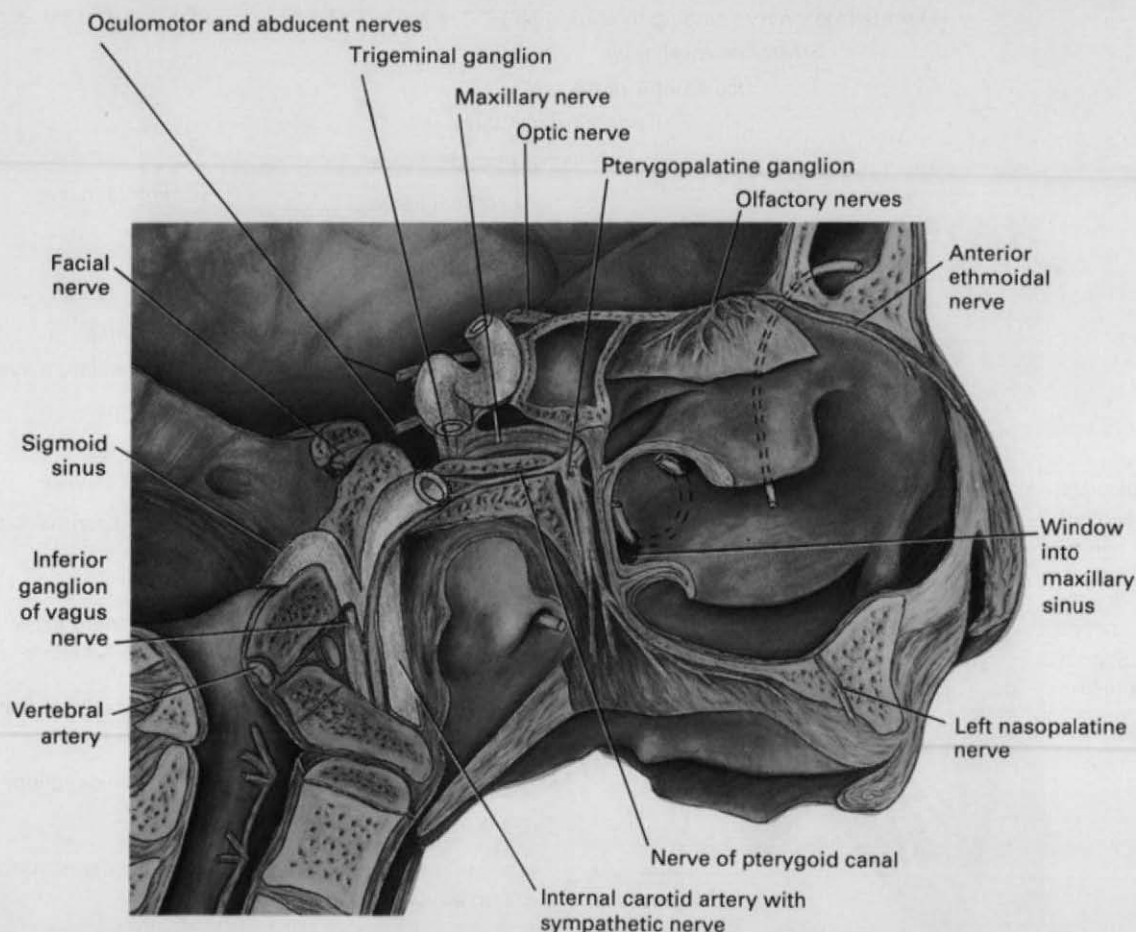


Fig. 6.19 Left pterygopalatine ganglion, seen from the medial (right) side in the left half of the skull. Behind the left nasal cavity the perpendicular plate of the palatine has been removed to open up the greater palatine canal, and the left sphenoidal sinus has been dissected away to show the pterygoid canal which is in the floor of the sinus. A bristle has been passed through the openings of the frontal sinus, and from the opening of the maxillary sinus into an artificial opening above the inferior concha.

glands of the palate, nose and paranasal sinuses. It is the ganglion of hay fever ('running nose and eyes'). Its connexions are summarized on page 34.

The ganglion lies immediately in front of the opening of the pterygoid canal, so that the nerve of that canal can run straight into the back of the ganglion. Because the canal is below and medial to the foramen rotundum (Fig. 8.7, p. 657) the ganglion is not suspended straight down from the maxillary nerve but lies below and medial to it. The connexion between the two is a surprisingly large single trunk (not double, despite the official term 'ganglionic branches').

The autonomic root is the **nerve of the pterygoid canal** (Vidian nerve). This nerve is formed in the foramen lacerum by union of the *greater petrosal nerve*

(p. 571), containing parasympathetic secretomotor fibres, with the *deep petrosal nerve*, containing sympathetic vasoconstrictor fibres. The latter is a branch given off from the carotid nerve in the foramen lacerum. The combined nerve passes forward in the pterygoid canal and joins the ganglion.

The secretomotor fibres to the lacrimal gland leave their cell bodies in the ganglion and join the maxillary nerve through the stout connexion, pass in its zygomatic branch into the orbit, join the lacrimal branch of the ophthalmic nerve and so reach the lacrimal gland.

The rest of the fibres in the connexion between the maxillary nerve and the ganglion are sensory and, like the sympathetic fibres in the deep petrosal nerve, they

pass through the ganglion without relay. The only cell bodies in the ganglion are parasympathetic (secretomotor). The five branches of the pterygopalatine ganglion are distributed to the nose and palate. *Every branch carries a mixture of all three kinds of fibres: sensory, secretomotor and sympathetic.*

The **nasopalatine nerve** (formerly the long sphenopalatine) passes through the sphenopalatine foramen, crosses the roof of the nose, and is distributed to the septum and incisive gum of the hard palate (p. 473).

The **lateral posterior superior nasal nerves** (formerly the short sphenopalatine) pass through the sphenopalatine foramen and turn forward to supply the posterosuperior quadrant of the lateral wall of the nose (p. 473).

The **greater palatine nerve** passes down through the greater palatine canal and at the greater palatine foramen turns forward to supply the mucous membrane of the hard palate (Fig. 6.19). Its nasal branches supply the posteroinferior quadrant of the lateral wall of the nose (p. 473). It gives branches to the medial wall of the maxillary sinus.

The **lesser palatine nerves**, two in number, pass down behind the greater palatine nerve and emerge through the lesser palatine foramina behind the crest of the palatine bone. They pass back to the soft palate and the mucous membrane of the palatine tonsil.

The **pharyngeal nerve** passes back through the palatovaginal canal, emerges at the roof of the nose and supplies the mucous membrane of the upper nasopharynx (p. 489). One or two very fine **orbital branches** enter the orbit via the inferior orbital fissure and supply part of the periosteum and also the orbitalis muscle and the mucous membrane of the sphenoidal and ethmoidal sinuses.

Maxillary vessels

The **maxillary artery** passes through the pterygo-maxillary fissure and enters the pterygopalatine fossa, lying just below the maxillary nerve, where it gives off five branches that pass with the five branches of the pterygopalatine ganglion.

Another branch, the **infraorbital**, passes through the inferior orbital fissure and accompanies the infraorbital nerve along the floor of the orbit and, almost spent, emerges on the face through the infraorbital foramen.

Veins accompany the above arteries and, passing through the fossa, emerge at the pterygomaxillary fissure to drain into the pterygoid plexus. In general, vessels in the fossa lie anterior to the nerves.

PART 11

NOSE AND PARANASAL SINUSES

The nose is for breathing; the design of its cavity results in warming and moistening the inspired air, and in cleaning it too. Since odours are airborne, the olfactory receptors are placed in the nose. The floor of the nose is the hard palate. Hence chewing can go on in the mouth cavity without interfering with breathing; the flap-valve of the soft palate meanwhile shuts off the mouth cavity from the airway through the oropharynx. Breathing is arrested during swallowing; the soft palate is elevated and shuts off the nose (i.e. the nasopharynx) from the foodway through the oropharynx. Thus the oropharynx is the crossroads of airway and foodway; collisions between air stream and food are avoided by the control mechanism of the soft palate acting as the policeman on point duty.

The **nose** consists of the *external nose* and the *nasal cavity*, which is divided into right and left halves by the midline *nasal septum*. Each half of the cavity has *olfactory*, *vestibular* and *respiratory parts* depending on the type of epithelial covering.

EXTERNAL NOSE

The **external nose** projects from the face; its skeleton is largely cartilaginous. Examine a skull. The *anterior nasal (piriform) aperture* is bounded above by the nasal bones and elsewhere by the two maxillae (Fig. 8.2, p. 644). The external nose consists of the *nasal bones* (the 'bridge' of the nose) and the *lateral* (upper) and *greater* (alar or lower) *nasal cartilages*, supported in the midline by the cartilaginous part of the *nasal septum*. A pad of fibrofatty tissue forms the lateral boundary of the nostril itself; this and the adjacent cartilage are moved by the compressor and dilator naris muscles. These and other very small cartilages are of the hyaline variety. The whole is covered by adherent skin that contains many sebaceous glands and internally its upper part is lined with respiratory mucous membrane. The skin extends into the *vestibule* within the nostrils and here has a variable crop of stiff hairs. The mucocutaneous junction lies beyond the hair-bearing area.

The **skin** is supplied by the external nasal nerve (the terminal part of the anterior ethmoidal), which notches the nasal bone and passes down on the upper and lower nasal cartilage to the tip of the nose, by the supra-trochlear and infratrochlear nerves (from the frontal

and nasociliary) above this and, around the nostrils, by nasal branches of the infraorbital nerve (Fig. 6.13A).

The *blood supply* is by the dorsal nasal artery (a terminal branch of the ophthalmic) at the base, and lower down by the external nasal (from the anterior ethmoidal) and by the lateral nasal and septal branches of the facial and its superior labial branch respectively.

NASAL CAVITY

The **nasal cavity** extends from the nostrils (anterior nares) to the posterior end of the nasal septum. Posteriorly it opens into the nasopharynx (p. 489) through the posterior nasal apertures.

Most of the cavity is the *respiratory area*, lined by respiratory mucous membrane with pseudostratified ciliated columnar epithelium. The surface area of the lateral wall is increased by the projection of the nasal conchae. The mucous membrane is very vascular, especially over the inferior concha, to warm the inspired air. Mucous secretion traps particulate matter, and the cilia beat the film of mucus back into the nasopharynx. The watery secretion of serous glands evaporates to moisten the inspired air.

The *vestibular area* is the region just inside the nostril, a centimetre or so in depth, lined not by respiratory mucosa but by skin (with hair follicles and glands) that has crept in from the face.

The *olfactory area*, which contains the receptors for the special sense of smell, occupies the roof and uppermost parts of the nasal septum and lateral wall, over but not below the superior concha.

The **floor** of the nose is the roof of the mouth—the hard palate. The lateral wall of the nose is, above, the medial wall of the orbit (the ethmoidal air cells intervening) and, below, the medial wall of the maxillary sinus. The floor of the sinus often lies at a lower level than the floor of the nasal cavity.

The lateral wall and septum are close together at the narrow **roof** (perhaps only 2 mm apart) and further apart at the broader floor. In cross-section the nasal cavity is pear-shaped, but three conchae project into it with increasing prominence from above down, so that the distances between conchae and septum are about equal (Fig. 6.20).

The framework of the **nasal septum** consists of the vomer, the perpendicular plate of the ethmoid and the septal cartilage (see below and Fig. 6.22). The cartilage extends forwards to give shape and prominence to the external nose. The septum is nearly always deviated from the midline. The mucous membrane (mucoperiosteum and mucoperichondrium) is firmly bound to the framework but can be readily stripped off from the

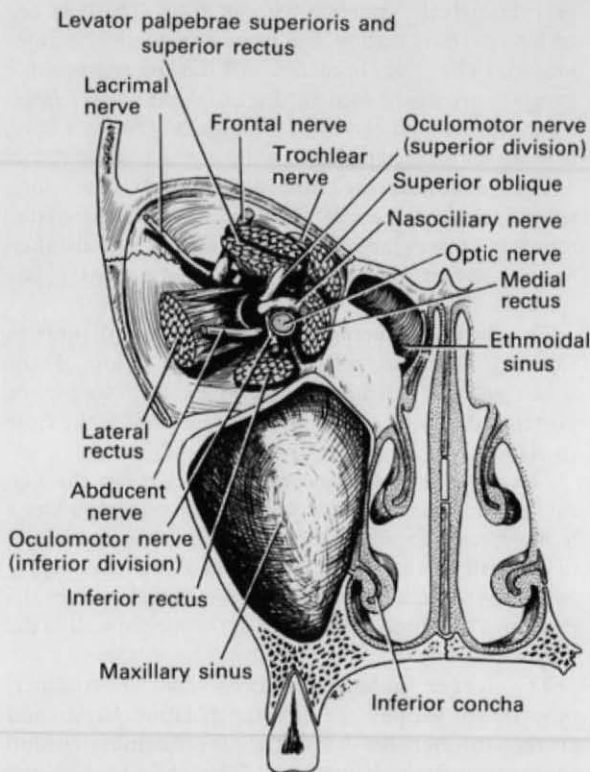


Fig. 6.20 Coronal section of the nasal cavity, right orbit and maxillary sinus, from the front at the level of the second premolar tooth.

cartilage, as in the operation of *submucous resection* (which should properly be called 'subperichondrial' resection).

The **lateral wall** should be studied in the intact specimen and in the dried skull (Fig. 6.22B). In the living it is covered with mucous membrane that is very vascular and adherent to the periosteum of the underlying bone.

The shape of the lateral wall is roughly *semicircular*, that is, highest halfway along, at the cribriform plate of the ethmoid. From the vestibule the roof curves up to this level; behind the cribriform plate the roof curves down over the body of the sphenoid into the nasopharynx (Fig. 6.21). The lateral wall is not vertical, but slopes up from the broad nasal floor to the narrow roof.

There are three **nasal conchae** (still often called by ENT surgeons by their old name of *turbinate bones*) projecting downwards like scrolls from the lateral wall. The lowest is the longest. The middle and upper are joined anteriorly, but diverge away from each other posteriorly. Beneath the free inferior border of each

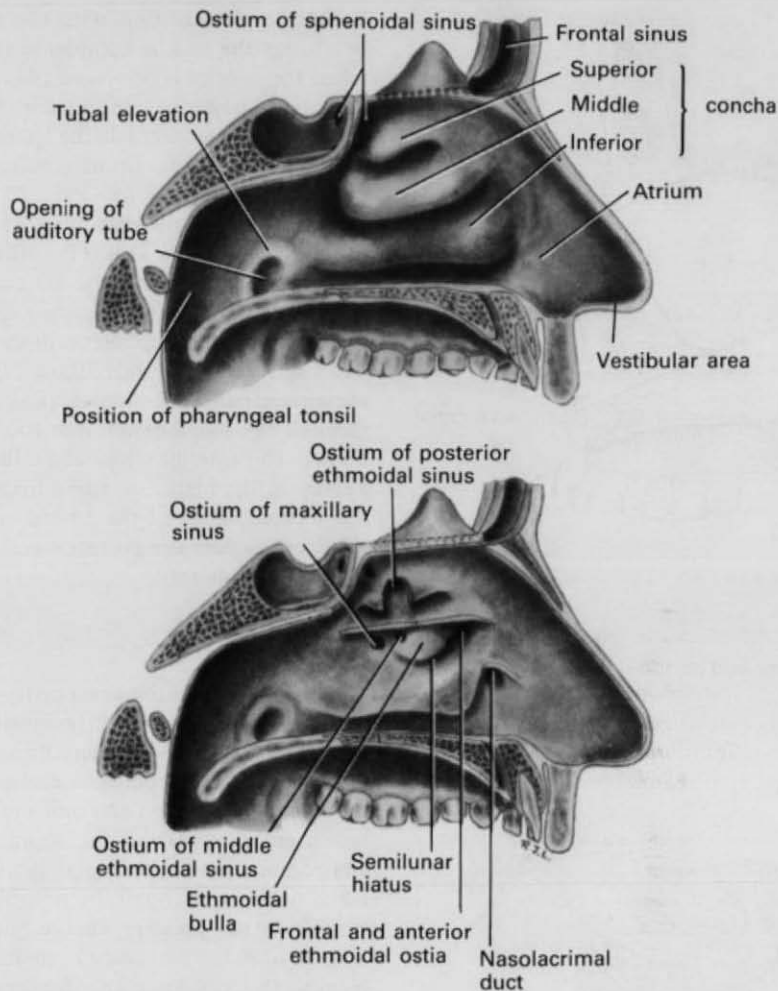


Fig. 6.21 Lateral wall of the left half of the nasal cavity and nasopharynx. In the lower figure parts of the conchae have been removed to show the openings of the sinuses and the nasolacrimal duct.

concha is a space, called superior, middle and inferior **meatus** respectively. Above the superior concha is the **sphenoethmoidal recess**. The sphenoidal sinus opens into this recess and the posterior ethmoidal air cells into the superior meatus. The nasolacrimal duct opens into the inferior meatus. The middle meatus receives *all the other openings* into the lateral wall (Fig. 6.21).

The **inferior concha** is the longest and broadest of the three conchae. It is covered with mucous membrane that contains large vascular spaces, erectile tissue that controls the calibre of the nasal cavity. It can swell and 'block the nose' rapidly. It overhangs the **inferior meatus**, which receives the nasolacrimal duct, draining excess tears from the eye. The duct opens

2 cm behind the nostril. About 1 cm behind the inferior concha (not in the nasal cavity but in the nasopharynx) is the opening of the auditory tube.

The **sphenoethmoidal recess** lies above and behind the superior concha. It receives the ostium of the sphenoidal air sinus. Strictly speaking the sphenoidal ostium is in the narrow roof rather than in the lateral wall (Fig. 6.22B).

The **superior concha** is small. It extends posteriorly from its junction with the middle concha. Its lower edge is free and overlies the **superior meatus**, into which drain the posterior ethmoidal air cells.

The **middle concha** is midway in size and position between superior and inferior. It extends horizontally

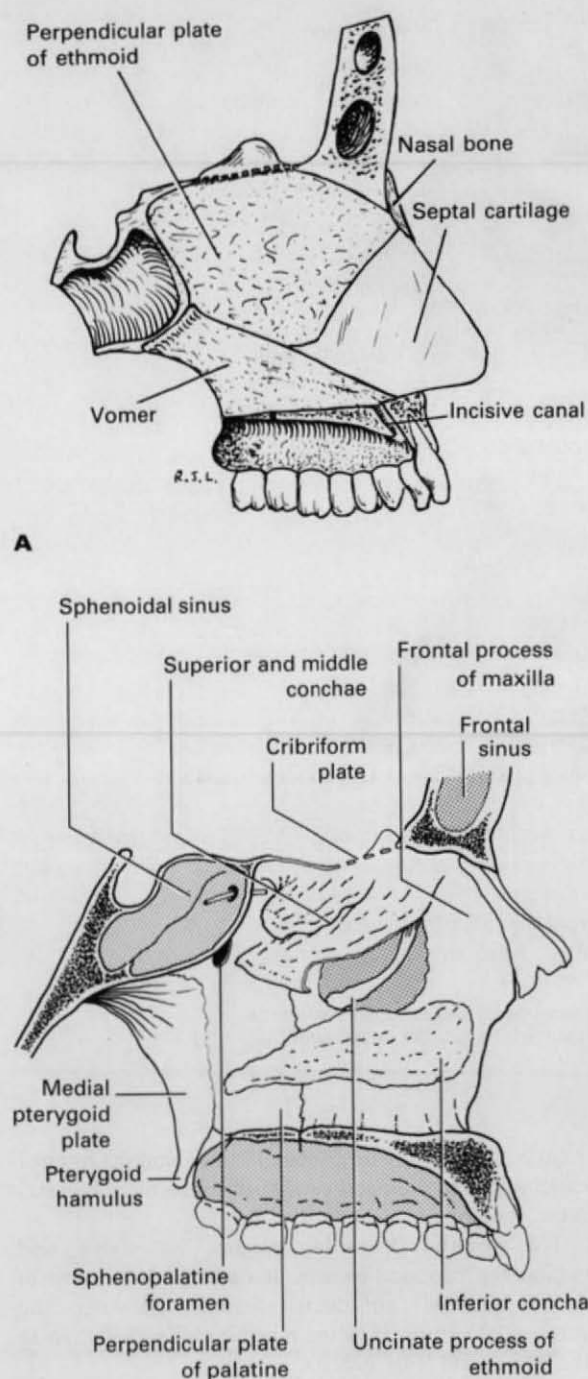


Fig. 6.22 Skeleton of the nose. **A** The nasal septum from the right. **B** The lateral wall of the left side of the nasal cavity. Part of the middle concha and the ethmoidal bulla have been removed to show the uncinate process of the ethmoid. There is a marker in the ostium of the sphenoidal sinus.

back from its junction with the superior concha. It overhangs the middle meatus, which can be seen only when the concha is displaced (Fig. 6.21). Immediately behind the posterior end of the middle concha beneath the mucous membrane is the sphenopalatine foramen. The flat area in front of the concha is the atrium of the nose.

The **middle meatus** presents a convex bulge beneath the concha. This is the **ethmoidal bulla** of the ethmoid, produced by the bulging of one or more middle ethmoidal air cells, whose ostium opens on the bulla, usually high up. Beneath the bulla is a semicircular slit, the **semilunar hiatus**, into which open the remaining paranasal sinuses. The frontal sinus opens through the *infundibulum* into the anterior end of the hiatus. The anterior ethmoidal cells open through ostia nearby in the hiatus or, quite frequently, directly into the infundibulum of the frontal sinus. The maxillary sinus opens near the posterior end of the hiatus, often by a double ostium.

Blood supply

The main artery of the nasal cavity is the **sphenopalatine**, which is the end of the maxillary artery that has changed its name on passing through the sphenopalatine foramen. It supplies the mucosa over the conchae and the meatuses, and also much of the septum. On the lower anterior part of the septum (Little's area) it anastomoses with the septal branch of the superior labial (entering through the nostril) and the ascending branch of the greater palatine (entering through the incisive canal—see below), so forming Kieselbach's plexus, the common site for epistaxis (nosebleed). Anterior and posterior ethmoidal vessels supply the roof and anterior part of the lateral wall.

Veins accompany the arteries and drain in various directions: to the pterygoid plexus via the sphenopalatine foramen, to the facial vein, to ophthalmic and inferior cerebral veins via the ethmoidal foramina and cribriform plate, and rarely (1%) to the superior sagittal sinus via the foramen caecum.

Lymph drainage

Lymphatics tend to run with the veins rather than arteries, and drain to submandibular, deep cervical and retropharyngeal nodes.

Nerve supply

The **olfactory area** of the roof, superior concha and corresponding part of the septum has the olfactory

receptors and the cell bodies of the bipolar cells embedded within the mucosa. The central process of the bipolar cells form the 20 or so filaments of the olfactory nerve which pierce the cribriform plate of the ethmoid to reach the anterior cranial fossa, where they synapse with the mitral cells of the olfactory bulb (p. 589). This olfactory area also contains fibres of ordinary sensation from adjacent areas.

The *vestibular area* is supplied by the infraorbital nerve whose branches have 'crept in' from the face. The rest of the lateral wall, the *respiratory area*, is supplied as follows: at the front by the anterior ethmoidal nerve (through its own foramen) in the upper part, and in the lower part by some filaments from the anterior superior alveolar nerve which pierce the wall of the maxillary sinus; at the upper back part by the lateral posterior superior nasal branches from the pterygopalatine ganglion (entering through the sphenopalatine foramen) and at the lower back part by the posterior inferior nasal branches of the greater palatine nerve (entering through their own minute foramina in the perpendicular plate of the ethmoid bone).

In contrast to the above total of six nerves supplying the lateral wall, the *septum* is supplied by four nerves: olfactory in the upper part, anterior ethmoidal at the front, medial posterior superior nasal at the back (via the sphenopalatine foramen), and the nasopalatine (formerly the long sphenopalatine) also entering through the sphenopalatine foramen and running to the front in the groove on the vomer to enter the incisive canal.

Sneezing. This protective reflex expels irritant material trapped in the nose. First there is a reflex secretion (no use to sneeze through a dry nose), then this secretion itself (as in coryza) initiates the sneeze reflex. The excess secretion with its trapped particles is blasted out of the nostrils. The soft palate controls the volume of the nasal blast, the rest of the compressed air escaping harmlessly through the mouth (see p. 476). The afferent path for the sneeze reflex involves the branches of the trigeminal nerve supplying the nasal mucosa, and the efferent nerves are similar to those for the cough reflex (p. 503).

OSTEOLOGY OF THE NOSE

Examine the longitudinal section of a skull made alongside the nasal septum.

The **septum** consists of the vomer, ethmoid and septal cartilage (Fig. 6.22A). The vomer is fixed to the rostrum of the sphenoid by its alae. It forms the posterior border of the septum and, slotted into a grooved ridge on the hard palate, extends like a ploughshare

forwards beyond the incisive canal. It is grooved on each side by the sphenopalatine vessels.

The perpendicular plate of the ethmoid forms a suture with the upper border of the vomer. It completes the posterior part of the bony septum, but falls short of the anterior extremity of the vomer. The septal cartilage fills the angle between the two bones.

The central part of the **roof** is the cribriform plate of the ethmoid. At the front, sloping downwards, are the nasal spine of the frontal bone and the nasal bone. At the back is the backward-sloping body of the sphenoid.

The **lateral wall** of the nose can only be studied adequately if the delicate bones have not been broken away. The frontal process of the maxilla and the nasal bones are in front. Behind them, study the lateral wall by building it up on the maxilla (Fig. 6.22B). The maxilla (carrying all the upper teeth) is stabilized laterally by the flying buttress of bone called the zygomatic arch (Fig. 6.14) and medially by the firm articulation of the palatal process with the opposite one.

The maxillary sinus opens on the medial wall of the maxilla by a large gap (Fig. 8.10, p. 660) which is made much smaller by the encroachment of parts of four neighbouring bones (palatine, inferior concha, ethmoid and lacrimal) and by mucous membrane unsupported by bone. The *palatine bone* sends a vertical plate across the posterior part of the maxillary hiatus. Between the two bones lies the greater palatine canal. The upper part of the perpendicular plate of the palatine bone is divided by a deep notch into orbital and sphenoidal processes which articulate with the maxilla in the apex of the floor of the orbit and with the body of the sphenoid bone (Fig. 8.12, p. 661). Thus is enclosed the *sphenopalatine foramen* which opens from the pterygopalatine fossa through the lateral wall of the nose just above the posterior end of the middle concha and just beneath the downward-sloping roof of the nasal cavity (Fig. 6.22B). Unlike the superior and middle conchae which are part of the ethmoid bone, the *inferior concha* is a separate bone. Its vertical maxillary process covers the lower part of the maxillary hiatus; the anterior part of the concha articulates with the conchal crest of the maxilla (Fig. 8.10, p. 660), the posterior part articulates with the conchal crest of the palatine bone (Fig. 8.11, p. 661). The *lacrimal bone* articulates with the frontal process of the maxilla and with the base of the inferior concha; the nasolacrimal duct is enclosed between them. The *ethmoid bone* articulates by its lateral mass (labyrinth) at the upper border of the maxillary hiatus. Below this level the uncinat process of the ethmoid curves back beneath the bulla to articulate with the base of the inferior concha. Between bulla and uncinat process lies the semilunar hiatus. The *medial pterygoid*

plate lies edge to edge behind the perpendicular plate of the palatine bone and completes the lateral wall of the nose.

The bones of the lateral wall are considered individually on page 659 et seq.

PARANASAL SINUSES

Certain bones that form the boundaries of the nasal cavities are hollowed out. The cavities so produced, the paranasal sinuses, are lined with respiratory mucous membrane, and they communicate by small apertures (ostia) with the nasal cavity. Prolonged nasal intubation may block the openings and lead to sinusitis. Their function is quite unknown. That they lighten the face bones is obvious enough, but a pair of spectacles and a pipe weigh down the head as much as sinuses full of cancellous bone would do. An elephant carries a pair of heavy tusks or a man on its head—it makes little difference to its neck muscles if its face bones are full of air or of bone marrow. When the sinuses are blocked or full of fluid the resonance of the voice is impaired, but it is difficult to imagine that the real purpose of such complicated structures is mere voice production. They are well developed in many silent animals. It may be that they serve as insulators to prevent incoming cold air from cooling down the surrounding parts, while the inspired air itself is being warmed and humidified by the conchae. Perhaps by their shape they help to determine the position of the orbital cavities and hence of the eyes.

All the sinuses are lined with respiratory mucous membrane, incorporating a sensory nerve supply; the region of the ostium is the most sensitive part, with the main part of each sinus being relatively insensitive. The glands produce a film of mucus which is moved by the cilia in spiral fashion towards the ostium. Gravity plays no part in draining a *normal* sinus (cf. trachea and bronchi).

There are four (bilateral) sinuses. The maxillary and ethmoidal sinuses are beyond the lateral wall of the nose. The frontal and sphenoidal sinuses abut at the midline, separated by a tiny bony septum that is almost always off centre, causing asymmetry of these sinuses.

Maxillary sinus

The **maxillary sinus** is the space within the body of the maxilla, known in earlier days as the maxillary antrum (of Highmore). The sinus is pyramidal in shape, the base at the lateral wall of the nose and the apex in the zygomatic process of the maxilla. The roof of the sinus is the floor of the orbit. The floor of the sinus is the alveolar part (tooth-bearing area) of the maxilla; it lies

at a lower level than the floor of the nose. Anterior and posterior walls are the corresponding walls of the maxilla. Certain ridges appear within the cavity; a constant one is at the junction of roof and anterior wall, produced by the downward passage of the infraorbital nerve within its canal (Fig. 8.10, p. 660).

The maxillary sinus is present at birth, but is no more than a shallow slit, slightly overgrown into a short cul-de-sac anteriorly and posteriorly. It excavates the lateral wall of the nose, beneath the middle concha, and lies just beneath the medial side of the floor of the orbit. The body of the neonatal maxilla lateral to this is full of developing teeth.

The sinus varies in size; a large one may extend into the zygomatic process of the maxilla and into the alveolar process so that the roots of the three molar teeth (and possibly of the premolars also) lie immediately beneath the floor or project into it. The roots are usually enclosed in a thin layer of compact bone; when this is absent the apex of the root is in contact with the mucous membrane. Extraction of such a tooth must leave a fistula by rupture of the mucous membrane. These fistulae mostly heal spontaneously.

The **ostium** of the sinus is *high up* and well back on its nasal wall. It is 2–4 mm in diameter. (A second smaller ostium often lies posteriorly.) It opens at the posterior end of the semilunar hiatus in the middle meatus of the lateral wall of the nose (Figs 6.21 and 6.18).

Blood supply. By small arteries that pierce the bone, mostly from the facial, maxillary, infraorbital and greater palatine arteries, and veins accompany these vessels to the facial vein and to the pterygoid plexus.

Lymph drainage. For the most part via the infraorbital foramen or the ostium; in either case the lymphatics flow to the submandibular nodes.

Nerve supply. By various branches of the maxillary nerve: superior alveolar (posterior, middle and anterior), the greater palatine and infraorbital.

The dental branches of the *posterior superior alveolar nerve* (p. 459) pass forwards in the bone above the apices of the molar teeth, which they supply. Minute branches pierce the bone to supply the mucous membrane of the sinus.

The *middle superior alveolar nerve* leaves the infraorbital nerve on the floor of the orbit and runs down in the lateral wall of the maxilla to supply the premolar teeth, and the overlying mucous membrane of the sinus. It forms loops in the bone with the posterior and anterior superior alveolar nerves (superior dental plexus). It is sometimes absent, in which case its supply to the teeth is usually taken over by the anterior superior alveolar nerve.

The *anterior superior alveolar nerve* leaves the infraorbital nerve in the infraorbital canal in the roof of the sinus. It passes laterally, then curves medially below the infraorbital foramen, in the anterior wall of the maxilla (Fig. 6.23). It supplies the pulps of the canine and incisor teeth, and the anteroinferior quadrant of the lateral wall of the nose, spilling over on to the floor of the nose and perhaps the septum anteriorly. Branches innervate the mucous membrane of the anterior wall of the sinus.

The *greater palatine nerve* in its canal gives off minute branches which perforate the maxilla to supply the posterior part of the medial wall of the sinus.

The *infraorbital nerve* gives perforating branches that supply the roof of the sinus.

Ethmoidal sinus

Each **ethmoidal sinus** lies between the orbit and the nose (Fig. 6.20), in the *ethmoidal labyrinth* (lateral part of the ethmoid bone). The sinus is not a single cavity, being divided by bony septa into a variable number of *ethmoidal air cells* (sometimes themselves called sinuses). There may be only 3 or as many as 18, each with their own ostium, and they are called anterior, middle or posterior according to where they drain (see below). The lateral wall of the labyrinth, in the medial wall of the orbit, is paper-thin (the *lamina papyracea*) and it is usually possible to see through it and distinguish some of the honeycomb-like air cells. The superior and middle nasal conchae project from its medial (nasal) wall. The labyrinth does not have its own roof but is

closed in by the orbital part of the frontal bone (Fig. 8.6, p. 656), whose medial edge articulates with the cribriform plate of the ethmoid. The anterior and posterior ethmoidal nerves pass between the roof of frontal bone and the ethmoid itself.

The *anterior ethmoidal air cells* occupy the anterior part of the sinus. Roofed in by the frontal bone, the bony walls are completed by the lacrimal bone. The *ostia* open into the anterior part of the semilunar hiatus in the *middle meatus*. A separate septum in the anterior part encloses a funnel-shaped canal (the *ethmoidal infundibulum*), which connects the frontal sinus above with the hiatus. The anterior ethmoidal cells may open into the infundibulum directly, instead of separately into the hiatus. One or more cells may lie in front of the frontonasal duct that drains the frontal sinus into the semilunar hiatus.

The *middle ethmoidal air cells* also drain into the *middle meatus*. One or more project as a convexity into the lateral wall of the nose under cover of the middle concha, forming the *ethmoidal bulla*. Ostia on its upper margin open into the *middle meatus*.

At the back of the labyrinth the *posterior ethmoidal air cells* are completed by fusion of the orbital process of the palatine bone and the sphenoidal concha (p. 657). They are roofed in by the orbital part of the frontal bone, between which and the lamina papyracea lies the posterior ethmoidal foramen whose opening in the medial wall of the orbit lies 1 cm behind its anterior companion, both transmitting the corresponding nerves and vessels. The posterior air cells drain into the *superior meatus*; this fact distinguishes them from middle air cells which open into the middle meatus. The most posterior air cell may extend far enough back to lie immediately adjacent to the optic nerve in its canal.

Blood supply. By branches from the supraorbital, anterior and posterior ethmoidal and sphenopalatine, i.e. from both the internal and external carotid systems.

Lymph drainage. To submandibular and retropharyngeal nodes.

Nerve supply. By small branches from various nerves which include the supraorbital, anterior ethmoidal, lateral posterior superior nasal, orbital and posterior ethmoidal. The significant feature is that the posterior cells may receive fibres from both the ophthalmic and maxillary branches of the trigeminal, with the possibility of referred pain to either branch.

Sphenoidal sinus

The pair of **sphenoidal sinuses** occupy the body of the sphenoid bone (Figs 6.21 and 8.7, p. 657). The two are separated by a septum which is usually not in the

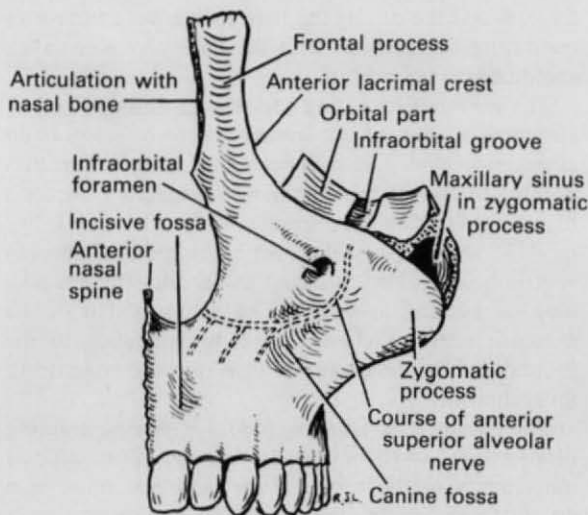


Fig. 6.23 Left maxilla from the front. The course of the anterior superior alveolar nerve is shown in broken line.

midline, and they can vary greatly in size. When small the sinus lies in front of the pituitary fossa; as it enlarges it lies beneath the fossa and may extend back into the basiocciput. A large sinus may also extend into the greater wing of sphenoid and pterygoid process.

A typical sinus is related above to the pituitary fossa and middle cranial fossa, and laterally to the cavernous sinus and internal carotid artery. Behind lie the posterior cranial fossa and pons, while below is the roof of the nasopharynx. Internally a large sinus may show a variable number of indentations or ridges produced by adjacent structures; in the roof, the pituitary gland and optic nerve; at the side, the internal carotid artery and maxillary nerve; and in the floor, the pterygoid canal with its nerve and the palatovaginal canal with the pharyngeal branch of the pterygopalatine ganglion.

The *ostium* is in the anterior wall of the sinus and opens into the *sphenoethmoidal recess* (behind the superior concha).

Blood supply. From the posterior ethmoidal and sphenopalatine branches of the maxillary artery.

Lymph drainage. To retropharyngeal nodes.

Nerve supply. By the posterior ethmoidal nerve and the orbital branch of the pterygopalatine ganglion (maxillary nerve).

Frontal sinus

The **frontal sinuses** are the only sinuses not present at birth; they appear during the second year as excavations into the *dipl e* of the frontal bone, and are really anterior ethmoidal air cells that have migrated upwards. Each extends above the medial end of the eyebrow into the squamous part of the frontal bone and backwards into the orbital part and so into the medial part of the roof of the orbit (Fig. 6.21). The two sinuses are unequal in extent and are separated by a bony septum in the midline region. The important relations are thus the anterior cranial fossa and the orbit. The sinus drains through an *ostium* at its lower medial corner into the front end of the semilunar hiatus, either via the ethmoidal infundibulum or by a separate channel, the frontonasal duct, through anterior ethmoidal air cells.

Blood supply. By supratrochlear, supraorbital and anterior ethmoidal arteries. Venous drainage is into diploic and superior ophthalmic veins.

Lymph drainage. Across the face to the submandibular nodes. Note the different drainage of the overlying eyebrow skin, which is to preauricular nodes.

Nerve supply. By the supraorbital and supratrochlear nerves by branches that pierce the frontal bone.

Development of the nose and sinuses

The development of the nose is considered on page 41.

The frontal sinus is absent and the remainder are rudimentary at birth. They continue to enlarge throughout life, but not at a constant rate — there are spurts of enlargement. From birth to adult life 'growth' of a sinus is due to enlargement of the bone that encloses it; in old age 'growth' of a sinus is due to resorption of surrounding cancellous bone.

Sinus	State at birth	Rapid enlargement	
Maxillary	Rudimentary	6–7 years	Postpuberty
Ethmoidal	Rudimentary	"	"
Sphenoidal	Rudimentary	"	"
Frontal	Absent (appears in 2nd year)	"	"

The early enlargement of all the sinuses coincides with the eruption of the second dentition. At this period the baby-face elongates and takes on more adult contours (see p. 47).

PART 12

MOUTH AND HARD PALATE

The **mouth** extends from the lips to the palatoglossal arches (anterior pillars of the fauces). It is enclosed by the lips and cheeks; the slit-like space between lips/cheeks and teeth/gingivae (gums) is the *vestibule of the mouth*. The space inside the teeth and gums is the *mouth cavity* proper. The floor is largely occupied by the tongue, and the roof is the hard palate; breathing goes on during mastication, with the flap-valve soft palate standing sentinel behind.

The mouth is for eating and talking through, and its structure is adapted accordingly. It serves also as an emergency airway in dyspnoea, but its structure has nothing to do with this function — it merely provides a bigger airhole than the narrow nostrils. The mobile lips (p. 477) are indispensable to articulate speech (except in ventriloquists). They are prehensile, too, for grasping food or sucking in liquid. The cheek pouch of the vestibule prevents chewed food from spilling to the ground and the buccinator returns it to the molar teeth for rechewing.

The tongue is for grasping food, for moving it during mastication, and for swallowing it. The delicate movements of the tongue turn laryngeal noise into articulate speech. In addition its mucous membrane is highly sensitive, even more than fingertips. It detects a fish bone and spits it out if nobody is looking, or feels a

hot potato and spits it out even if people are looking. It is better than a fingertip, for it possesses also the sense of taste, to accept or reject what is in the mouth. The tongue is the mouth; all the rest is accessory.

The *mucous membrane* of the mouth is adherent to the deeper structures: on lips and cheek to the face muscles, on tongue to the muscles thereof, on the hard palate to the periosteum of the bone. It is therefore seldom caught between the teeth when chewing. It is covered with stratified squamous epithelium and is supplied by the trigeminal nerve — above by the maxillary nerve and below by the mandibular nerve.

The lips and cheeks are covered with *hairy skin*, except for the *red margin* of the lips, which is devoid of hair. Their substance consists of the facial muscles in cadaverous individuals, added to by fat in the plump-faced. The groove between the buccinator and the anterior border of the masseter contains an encapsulated mass of fat, the *suctorial pad*, in the newborn. This pad often persists into adult life and does not shrivel even when, for any cause, the individual loses the rest of his body fat. It helps to prevent indrawing of the cheeks during sucking.

The mucous membrane (red border) or the margin of the lips is highly sensitive and is represented by a large area in the sensory cortex. It is the main exploratory sensory area in babies, before they learn to use their hands for stereognosis.

VESTIBULE OF THE MOUTH

This is a closed space, lips and cheeks lying in contact with the teeth and gums. It leads, by the space behind the molar teeth, into the cavity of the mouth and in the rest position, with the teeth slightly parted, it communicates all round, between the teeth, with the mouth cavity.

On the mucous membrane of the cheek the **parotid duct** opens on a low papilla opposite the *second upper molar tooth*. Nearby are the tiny openings of the ducts of the *molar glands*. These are four or five small mucous glands lying on the outer surface of the buccinator near the parotid duct and their ducts pierce the muscle to reach the mucous membrane of the vestibule. There are many other mucous glands (*buccal* and *labial*) scattered in the vestibule, especially in the lower lip. Unlike the molar glands they all lie internal to the face muscles, in the mucous membrane of the vestibule. Many of them are visible ('sago granules'). They are palpable to the examining finger or to the individual's own tongue. The orifices of their tiny ducts are too small to see. (Submandibular and sublingual salivary secretions drain into the mouth cavity proper — see below.)

Nerve supply. Much of the mucous membrane of the inside of the cheeks and lips is supplied by the *buccal*

branch of the *mandibular nerve*, with contributions from the *mental* branch of the *inferior alveolar* (also mandibular) and the *infraorbital* branch of the *maxillary nerve*; the last two supply the red margin of the lower and upper lips respectively.

Gingivae

The **gingivae** (the proper name for the gums) are firmly attached to the alveolar margins of the jaws and surround the necks of the teeth. They consist of dense but vascular *fibrous tissue* with an overlying epithelium that is *stratified squamous* and thinly *keratinized*. With alveolar resorption (as after tooth extraction and in old age) the gingivae conform to the new bony outline. The change from alveolar mucosa (continuous with that of the cheek) to gingival mucosa takes place 3–4 mm from the vestibular reflexion and is indicated by an abrupt change of colour: from transparent red alveolar to more opaque and less shiny gingival.

Nerve supply. The upper gums are supplied by the *superior alveolar*, *greater palatine* and *nasopalatine nerves* (maxillary), while the lower receive their innervation from the *inferior alveolar*, *buccal* and *lingual nerves* (mandibular). Note that, while the buccal nerve spills over from the cheek on to the lower jaw, it does not usually innervate the upper gums.

TEETH

The bulk of a tooth consists of **dentine**, a hard avascular calcified tissue penetrated by minute canals, the *dentinal tubules*. The part of the tooth that projects into the mouth is the **crown** which is covered by **enamel**, the hardest of all calcified animal tissues, and the part held in the jaw is the **root** which is covered by **cementum**, a calcified tissue rather like bone. The term 'clinical crown' refers to the part of the tooth seen in the mouth and does not exactly correspond to the enamel-covered 'anatomical crown' whose lower part is obscured in the gingival sulcus by the free gingival margin of the gum. The junction between enamel and cementum is the cervical margin or **neck**, which forms a slightly narrowed 'waist' to the tooth. Because enamel and cementum meet, dentine is not exposed on the surface. Inside the dentine is the **pulp cavity**, which communicates with the exterior via the *root canal* and the *apical foramen* at the apex of the tooth. The cavity is filled by **dental pulp**, with nerves (below), blood vessels (p. 459) and lymphatics (p. 435), all of which gain access to the pulp through the apical foramen. The pulp is covered with a single layer of tall columnar cells, the *odontoblasts*, lying in contact with the inner surface

of the dentine. Throughout life they retain the power to produce dentine within the pulp cavity if the surface of the dentine is breached. The odontoblasts give off fine cytoplasmic processes that occupy the dentinal tubules.

The **periodontal ligament** holds the cementum to the bony walls of the tooth socket. It consists of collagen fibres passing obliquely from the alveolar bone towards the apex of the tooth; the fibres 'sling' the tooth in position against pressure on its occlusal surface. It is really the modified periosteum of the alveolar bone. The ligament is radiolucent; in a radiograph of the tooth it shows as a clear interval between tooth and bone shadows.

Permanent dentition

The human adult has from the midline 2 incisors, 1 canine, 2 premolars and 3 molars; that is, 8 teeth in each half-jaw, or 32 teeth in all. The shape of a tooth is adapted to its function. The incisors are for biting and cutting, the canines for holding (well developed in carnivores) and the premolars and molars for chewing. In clinical dentistry it is common to refer to teeth by number (1 to 8 starting from the midline) rather than by name, e.g. upper right 5 is the upper right second premolar.

The teeth can be distinguished from one another by the characteristics of their roots and crowns. The *upper molars* have *three roots* each, two on the convexity and one on the concavity of the curve of the alveolar margin. The *lower molars* have *two roots* each, one anterior and one posterior. All the *other* teeth have but a *single root*—though a bifid root is not uncommon, especially in the first upper premolar.

The *incisor crowns* are chisel-shaped, adapted for biting. Upper and lower incisors do not meet edge to edge, but by a sliding overlap, like the blades of a pair of scissors. The *canine crowns* are pyramidal or conical, much more rugged than the incisor crowns. The *premolar* teeth have two cusps (lingual and buccal), whence their name of *bicuspid teeth*. *Upper molars* have *four*, *lower molars* *five*, cusps on their crowns.

Nerve supply

The term nerve supply of a tooth really means the nerve supply of the pulp; some fine nerve filaments may enter some dentinal tubules, but most of the dentine and all enamel and cementum have no innervation.

The pulp and periodontal ligament share the same nerve, which does *not* necessarily supply the overlying gum (p. 477).

In the *upper jaw* the molars are supplied by the dental

branches of the *posterior superior alveolar nerve*. The anterior buccal root of the first molar is supplied by the *middle superior alveolar nerve*, which supplies also the two premolars. The canine and incisor teeth are supplied by the *anterior superior alveolar nerve*. There may be variations from the above common pattern.

In the *lower jaw* the three molars and two premolars are supplied by the main trunk of the *inferior alveolar nerve*, whose terminal incisor branch supplies the canine and both incisors, overlapping to the opposite central incisor.

Dental anaesthesia

The alveolar bone of the maxilla is relatively porous, so anaesthetic solution deposited in the gingivae opposite the apex of a tooth root will readily penetrate the bone to anaesthetize the tooth for dental procedures. Infiltration of the buccal aspect of the jaw will allow painless drilling of the tooth, but for extraction the palatal aspect must be infiltrated as well.

For the teeth of the lower jaw **infiltration anaesthesia** is usually effective only for the incisors. The other mandibular teeth are embedded in bone that is denser and does not allow sufficient penetration of the anaesthetic agent. For these teeth, **inferior alveolar nerve block** is required; for extraction it is necessary to include block of the nearby lingual and buccal nerves as well in order to anaesthetize the adjacent soft tissues.

For *infiltration anaesthesia* on the buccal (outer) aspect of the jaw, the needle is inserted opposite the appropriate tooth just below or into the buccal fold (where the mucosa is reflected between jaw and cheek), with the tip of the needle directed to the level of the apex of the tooth. On the palatal side, the point of insertion of the needle is midway between the gingival margin and the midline of the palate.

For *inferior alveolar and lingual nerve block*, the needle is inserted through the buccinator above the level of the occlusal surface of the molar teeth and in front of the pterygomandibular raphe, which raises a visible and palpable ridge in the opened mouth, just behind the (palpable) internal oblique ridge of the mandibular ramus (Fig. 8.14, p. 664). The line of approach is from the premolar teeth of the opposite side, and a small injection is made 0.5 cm from the surface, when the needle is above the lingual nerve; the main injection is made another 1 cm deeper above the lingula, where the inferior alveolar nerve enters the mandibular foramen.

Tooth position

The teeth of the upper jaw lie in a continuous curve,

like a horseshoe. In the alveolar bone the outer (buccal) plate is thinner than the inner (palatal) plate. In the lower jaw the curve of the anterior teeth straightens out in the molar region. In the alveolar bone of the mandible the labial (outer) plate is thinner than the lingual (inner) plate over incisors, canines and premolars, but in the posterior molar region the lingual plate is thinner than the buccal.

The attachment of mylohyoid is below the apices of most of the mandibular teeth—an apical abscess thus points in the mouth. In the second and third molars the apices lie below the mylohyoid line—an apical abscess bursting through the inner plate points in the neck.

The upper teeth make a *larger curve than the lower*. The upper incisors lie in front of the lower in the closed position. The upper canine lies just behind the lower, in front of the first premolar, to their outer (buccal) side. The palatal cusps of the upper premolars and molars lie in the groove between lingual and buccal cusps of their opposite members, and each upper tooth articulates with its opposite member and the tooth behind that.

Deciduous dentition

The deciduous, or milk, teeth begin to erupt at about the sixth month and are completely erupted at the end of the second year. They consist of 5 teeth in each half-jaw, 20 in all. There are 2 incisors, 1 canine and 2 molars. They are shed as the permanent teeth erupt. Note that the deciduous molars are replaced by the permanent *premolars*, not by permanent molars which have no counterpart in the deciduous dentition.

Development and eruption of teeth

Teeth are derived by budding of the epithelium (ectoderm) lining the mouth. The buds of *ectoderm* produce only the *enamel*; they evoke a reaction in the surrounding *mesoderm*, which differentiates to produce the *dentine* and *cementum*.

In the mouth cavity (stomodeum) of the 5-week embryo [12 mm ($\frac{1}{2}$ inch) long] an ingrowth of ectoderm occurs over the site of the future gums. A curved sheet of ectoderm grows into the adjacent mesoderm, tilting medially. This is the *primary dental lamina*. From its outer surface a series of buds grow into the mesoderm—one for each deciduous tooth. At a later stage a similar series of buds grow (more medially) from the depths of the primary dental lamina—one bud for each permanent tooth. These epithelial buds are the *tooth germs* and when they are well formed the primary dental lamina becomes absorbed. Remnants of this epithelium may later grow into cysts or tumours.

The tooth germs grow away from the mouth surface into a wineglass-shaped mass, attached by its stalk to the primary dental lamina. This mass is the *enamel organ*. Its surface epithelium becomes columnar; the cells lining the concavity are **ameloblasts** which produce enamel. The epithelium of the rest of the enamel organ takes on a different appearance; its cells develop long branching processes and fluid separates them. From this appearance the mass is known as the *stellate reticulum*. After the ameloblasts commence to secrete enamel the stellate reticulum undergoes atrophy. Beyond the stellate reticulum the enamel organ is prolonged as an epithelial sheath around the root.

The mesoderm within the cavity of the wineglass-shaped enamel organ is evoked to differentiate into the *dental papilla*. Its surface cells become the columnar **odontoblasts** which produce dentine.

The ameloblasts (ectodermal) lining the concavity of the enamel organ and the odontoblasts (mesodermal) covering the convexity of the dental papilla lie in contact. Though the ameloblasts were there first, so to speak, it is the odontoblasts that become active first, producing dentine and, later, the ameloblasts produce enamel. As the two substances accumulate, the secreting cells are pushed further away from the amelodentinal junction. Around the root the dentine is contained by the epithelial sheath prolonged down from the enamel organ.

The mesoderm of the dental papilla persists as the pulp of the tooth, surrounded by the dentine it has secreted.

Cementum is produced in the mesoderm outside the dentine of the root. The process is comparable to membranous ossification. As the cementum is formed the epithelial sheath around the dentine is absorbed and the cementum becomes firmly bound to the dentine of the root.

The crown of the tooth is fully formed before eruption, but the root is only one-third formed. At this stage the tooth lies within a fibrous tissue condensation within the bone of the jaw, the *dental follicle*, and in the permanent teeth it communicates by a tiny orifice with the surface of the bone. The fibrous tissue in this orifice is the *gubernaculum*.

The tooth erupts by a combination of elongation of the root and absorption of the overlying bone. The elongating root is ensheathed in an upgrowth of alveolar bone.

The normal times of eruption are:

Deciduous teeth

6 months	Lower central incisors
7 months	Upper central incisors

8 months	Upper lateral incisors
9 months	Lower lateral incisors
1 year	First molars
18 months	Canines
2 years	Second molars

Permanent teeth

6 years	First permanent molars
7 years	Central incisors
8 years	Lateral incisors
9 years	First premolars
10 years	Second premolars
11 years	Canines
12 years	Second permanent molars
18 years plus	Third permanent molars (wisdom teeth)

A lower tooth precedes its opposite number in the upper jaw. The first permanent molar (the 6-year molar) erupts before any deciduous teeth have been shed. The second permanent molar does not erupt until 12 years of age. In the intervening period the five deciduous teeth in each half-jaw are replaced. The order of replacement is first the incisors, central and lateral, then the milk molars, first and second and, last of all, the long-rooted canine.

CAVITY OF THE MOUTH

The *palate* is the roof of the mouth. Between the teeth it lies on a basis of bone, the hard palate. Behind the teeth and hard palate the soft palate projects down.

The **hard palate** is made up of the palatal process of the maxilla and the horizontal plate of the palatine bone. (The part of the maxilla that bears the incisor teeth probably represents the mammalian premaxilla.) In the midline at the front of the hard palate lies the incisive fossa, into which open the incisive foramina (the ends of the incisive canals). The greater palatine foramen lies between the palatine bone and maxilla, level with the last molar tooth; the lesser palatine foramina, just behind it, perforate the palatine bone itself.

The **mucous membrane** of the front of the hard palate is strongly united with the periosteum and the two cannot be stripped apart. Together they can be readily stripped from the bone; these combined layers are the **mucoperiosteum**. The attachment of the periosteum to the bone is secured by multiple fibrous tissue pegs (Sharpey's fibres) that leave a finely pitted bone surface on the dried skull. This fixation of the mucous membrane is for mastication; the moving bolus does not displace the mucous membrane. There are

transverse masticatory ridges in this part of the mucoperiosteum. Over the horizontal plate of the palatine bone mucous membrane and periosteum are separated by a mass of mucous gland tissue; no large Sharpey's fibres are needed here, and the bone surface is smoothly polished. From between these areas the mucous membrane curves down to the under surface of the soft palate.

Blood supply. By the greater palatine artery, which emerges from the greater palatine foramen and passes around the palate (lateral to the nerve) to enter the incisive foramen and pass up into the nose. Veins accompany the artery back to the pterygoid plexus. Other veins pass back to the supratonsillar region and join the pharyngeal plexus.

Lymph drainage. To retropharyngeal and deep cervical lymph nodes.

Nerve supply. By the *greater palatine nerve* (from the maxillary via the pterygopalatine ganglion) as far forward as the incisive foramen. The anterior part of the palate, behind the incisor teeth (the area of the premaxilla), is supplied by the two *nasopalatine nerves*, from the same source.

Development of the palate. See page 41. The **soft palate** belongs to both the mouth and the pharynx. It forms the posterior sloping part of the roof of the mouth and part of the anterior wall of the pharynx. Because its musculature is more intimately connected with the pharynx than with the mouth it is more conveniently described with the pharynx (p. 491).

TONGUE

The **tongue** is essentially a mass of skeletal muscle mostly covered by mucous membrane, and with a midline fibrous septum separating the two muscular halves. The main parts are the dorsum, tip, inferior surface and root. The *dorsum* faces in two directions: its anterior two-thirds or oral part upwards towards the hard palate, and its posterior one-third or pharyngeal part (sometimes called the base) backwards, forming the anterior wall of the oral part of the pharynx. The *tip* is the most anterior and most mobile part and merges into the *inferior surface*. The mucous membrane of this inferior surface and of the floor of the mouth is thin and smooth, similar to that of the cheek; it projects as a midline flange, the frenulum, beneath the tip of the tongue. The mucous membrane on the oral and pharyngeal parts has different developmental origins and surface appearances, and each has a different function; the oral part grips for chewing and the pharyngeal part is smooth for swallowing.

The oral **anterior two-thirds** of the tongue (*presulcal*

part) is covered by mucous membrane into which the underlying muscles are inserted. The surface epithelium is of the stratified squamous keratinizing variety and is roughened by the presence of many **papillae**. In man these are of three types; filiform, fungiform and vallate. The *filiform* type give rise to the velvety appearance (the 'fur' of the tongue), and provide a non-slip surface for moving a food bolus. *Fungiform papillae* are visible in the living tongue as discrete pink pinheads (whitish in the cadaver), and are more numerous towards the edges of the tongue; each bears a few taste buds (there are none on filiform papillae). The *vallate papillae* are about a dozen in number and are arranged in the form of a V with the apex pointing backwards, just in front of an ill-defined shallow groove, the *sulcus terminalis*, which marks the junction of the oral and pharyngeal parts of the tongue (but see Nerve supply, below, for discussion of this point). There are many taste buds in the epithelium lining the crevice that surrounds each vallate papilla. The papillae are far back on the oral surface and so not in contact with the food being chewed, but food juices and saliva reach them and so flavours are transmitted to them.

There are no glands on the dorsum of the anterior two-thirds of the tongue, but there are scattered mucous and serous glands under the tip and sides. On the under surface behind the tip there is a rather large mixed gland, the *anterior lingual gland*, on each side of the midline. From each gland half a dozen tiny ducts open on the under surface of the tongue.

The **posterior third** of the tongue (*postsulcal part*) is really part of the pharynx, but it is obviously convenient to study it with the rest of the organ as part of the mouth. It extends from the *sulcus terminalis* to the epiglottis. At the apex of the *sulcus* is a small depression, the *foramen caecum*, which is the remains of the upper end of the thyroglossal duct (thyroid diverticulum, p. 39). There are no papillae behind the *sulcus*. The smooth mucous membrane has a nodular appearance from the presence of underlying masses of mucous and serous glands and aggregations of lymphoid follicles. The latter constitute the 'lingual tonsil', part of Waldeyer's ring (p. 490). This posterior part of the tongue, like the soft palate above it, is coated with mucus from its multiple glands and makes a smooth and slippery surface for swallowing. Between the tongue and epiglottis a midline flange of mucous membrane is raised up between the two as the *median glossoepiglottic fold*. From each side of the epiglottis a similar mucosal fold extends laterally to the wall of the pharynx as the *lateral glossoepiglottic fold*, but this is a misnomer because it is not attached to the tongue and would be better named pharyngoepiglottic. Its frame-

work is fibrous tissue joining the epiglottis to the greater horn of the hyoid bone. The three folds enclose the two *valleculae*, shallow oval pits behind and below the posterior end of the tongue.

When the tip of the tongue is raised to the roof of the mouth, the **inferior surface** of the tongue can be inspected. A small midline septum of mucous membrane (lingual frenulum) unites it to the floor of the mouth. Lateral to this the deep lingual vein can usually be seen through the mucosa (the lingual artery and nerve that are near it are not visible), and farther laterally still is another fold of mucosa, the fimbriated fold.

The **palatoglossal arches** (formerly called the anterior pillars of the fauces) are ridges of mucous membrane raised up by the palatoglossus muscles (see below). They extend from the under surface of the front of the soft palate to the sides of the tongue at the vallate papillae. The whole constitutes the **oropharyngeal isthmus**. In front of it is the mouth, behind it is the pharynx; and it is narrower than either. It is closed by depression of the palate and elevation of the dorsum of the tongue, and narrowed by contraction of the palatoglossus muscles.

Muscles

The muscles of the tongue are divided into intrinsic and extrinsic groups; the *intrinsic muscles* are wholly within the tongue and not attached to bone, while the *extrinsic muscles* have a bony attachment. There are four muscles in each group in each half of the tongue, with a midline fibrous *septum* dividing the organ into two symmetrical halves. The muscles of the intrinsic group are the *superior* and *inferior longitudinal*, *transverse* and *vertical*, and the extrinsic group comprises genioglossus (which is the largest of all the muscles and makes up the bulk of the tongue), hyoglossus, styloglossus and palatoglossus. From their names it is apparent that the extrinsic muscles have attachments to the hyoid bone, hard palate and styloid process, but it should be noted that genioglossus might be better named geniohyoglossus since it is attached to the hyoid bone as well as to the mandible.

Genioglossus arises from the superior mental spine (formerly the genial tubercle), whence the fibres radiate widely to be inserted into the mucous membrane of the tongue, with the lowest fibres passing down to the hyoid bone.

Hyoglossus arises from the length of the greater horn of the hyoid bone and from its body lateral to geniohyoid. It extends upwards as a thin quadrilateral sheet; its upper border, interdigitating at right angles with the fibres of styloglossus, is attached to the side of the tongue. Its anterior and posterior borders are free.

The muscle is a key structure for the side of the tongue, and its *posterior border in particular is an important landmark* in dissections, especially when the body of the mandible has been removed (Fig. 6.17). *Superficial* (lateral) to the muscle from above downwards lie the lingual nerve, submandibular duct and hypoglossal nerve, while passing *deep* to its posterior border from above downwards are the glossopharyngeal nerve, stylohyoid ligament and lingual artery (p. 484).

Styloglossus arises from the front of the lower part of the styloid process and the upper part of the stylohyoid ligament. It passes forwards below the superior constrictor to be inserted into the side of the tongue, interdigitating with the upper fibres of hyoglossus. The glossopharyngeal nerve curves parallel with its lower border on a slightly deeper plane.

Palatoglossus descends from the under surface of the palatine aponeurosis to the side of the tongue, forming with its fellow of the opposite side the palatoglossal arch (see above), which is the dividing line between mouth and pharynx. It is described further with the soft palate (p. 494).

Blood supply

The tongue is supplied by the **lingual artery** (p. 437), which runs above the greater horn of the hyoid bone deep to hyoglossus and passes forwards to the tip. Beneath hyoglossus it gives off *dorsal lingual* branches into the posterior part. At the anterior border of hyoglossus it gives a branch to the sublingual gland and the floor of the mouth. There are small contributions from the tonsillar branch of the facial artery and from the ascending pharyngeal artery. The fibrous septum dividing the two halves of the tongue prevents any significant anastomosis of blood vessels across the midline.

Venous tributaries accompanying the lingual artery and its dorsal branches form the **lingual vein**. The venous return from the tip is by the *deep lingual vein*, visible on each side of the midline on the under surface. It runs back superficial to hyoglossus and is joined at the anterior border of that muscle by the *sublingual vein* (from the sublingual gland) to form the *vena comitans of the hypoglossal nerve*. It continues backwards close to the nerve and has a variable ending, joining either the lingual, facial or internal jugular veins. The lingual vein usually joins the internal jugular near the greater horn of the hyoid bone.

Lymph drainage

The most significant feature of the tongue's lymph

drainage (Fig. 6.24), which is through the floor of the mouth, is that lymph from one side, especially of the posterior part, may reach nodes of both sides of the neck (in contrast to the blood supply which remains unilateral). However, this contralateral flow usually only occurs when the ipsilateral channels have become obstructed. The tip is said to drain to submental nodes but these are rarely affected by lingual disease in this part. The rest of the anterior part drains to submandibular nodes (Fig. 6.24), and then to nodes of both the upper and lower end of the deep cervical group. The posterior part drains directly to deep cervical nodes.

Nerve supply

All the *muscles* of the tongue, intrinsic and extrinsic, are supplied by the **hypoglossal nerve** (except palatoglossus, which, being essentially a palate muscle, is supplied by the pharyngeal plexus, p. 495). The motor cell bodies are in the hypoglossal nucleus, below the hypoglossal trigone in the medullary part of the floor of the fourth ventricle (p. 614). The pathway of proprioceptive impulses from the tongue is probably via the lingual nerve.

Contrary to the most common statements on the subject, the *sensory supply* of the mucous membrane of the tongue is from *three* nerves, not two (because the mucosa is developed from three pharyngeal arches—see below). The *oral part* (presulcal, anterior two-thirds), but not the region of the vallate papillae, is supplied by the **lingual nerve**, whose trigeminal

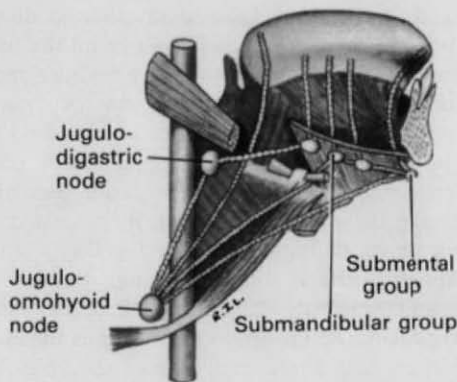


Fig. 6.24 Lymph drainage of the tongue. Of the deep cervical nodes, only the jugulodigastric and jugulo-omohyoid nodes are shown; other channels drain to other nodes of the group.

component mediates common sensibility (with cell bodies in the trigeminal ganglion) and whose **chorda tympani** component mediates taste (with cell bodies in the genicular ganglion of the facial nerve). The parasympathetic secretomotor fibres to the anterior lingual gland run in the chorda tympani from the superior salivary nucleus, and relay in the submandibular ganglion.

The *posterior one-third* of the mucosa, together with the presulcal area that includes the vallate papillae, is mainly supplied by the **glossopharyngeal nerve**. This has fibres of both common sensibility and taste (with cell bodies in the glossopharyngeal ganglia in the jugular foramen), and carries parasympathetic secretomotor fibres to the mucosal glands (with relay in lingual ganglia within the mucosa). A small area of lingual mucosa forming the anterior wall of the vallecula is supplied by the nerve of the vallecular mucosa, the **internal laryngeal** (with cell bodies in the inferior vagal ganglion). Thus the mucous membrane in the region of the vallate papillae, which lies in front of the sulcus terminalis and therefore in the oral (presulcal) part, is supplied by the main nerve of the pharyngeal (postsulcal) part, the glossopharyngeal. This can be explained by the forward migration of epithelium from the postsulcal part during development. There is no landmark on the dorsal surface of the tongue to indicate where lingual and glossopharyngeal supplies meet. For the explanation of these nerve supplies, see below.

Vasoconstrictor sympathetic fibres travel with the lingual artery from the external carotid plexus; their cell bodies are in the superior cervical ganglion.

Structure

The substance of the tongue is composed of fibres of striated muscle lying for the most part in three planes at right angles to each other. Mucous and serous glands are abundant in the posterior part. Lymphoid follicles occur here and constitute the lingual tonsil; there are none in the anterior part. The surface is covered by a stratified squamous epithelium which, in the mouth part, is projected into papillae.

The *filiform papillae* are by no means thread-like, but project as truncated cones whose flat tops are covered with keratin. The appearance of the protruded tongue depends on the state of the keratin. When there is little keratin (as after chewing roughage) the tongue is a 'healthy' pink. When the keratin is thick (as from lack of chewing in illness, starvation) it becomes white by maceration ('washerwoman's fingers'). Keratin dries

after mouth breathing and is then brown in colour. The *fungiform papillae* are so scanty as to be seldom seen in random sections of the tongue; they have a slender base and bulbous tip which is not keratinized. A *vallate papilla* consists of a cylindrical mass about 2 mm in diameter surrounded by a deep slit, both walls of which contain taste buds. The ducts of serous glands open into the base of the slit, to wash it out ready to taste the next arrival.

Taste buds lie as spherical masses entirely within the epithelium; they are seldom seen except in the walls of vallate papillae, where they abound. A taste bud is made up of slender, spindle-shaped, pale cells some of which are the *receptor cells*. It opens on the surface by a tiny gustatory pore.

Movements

The tongue is used in sucking, in prehension of food, in chewing, in swallowing and in speaking. It is also used in toilet (licking the lips in man, licking the fur in animals) and occasionally in gesture. Its moist 'fur' makes an excellent damping pad for licking.

The intrinsic muscles alter the *shape* of the tongue, the extrinsic muscles stabilize the organ and by their contraction alter its *position*, as well as its shape. The tongue rests on the floor of the mouth (p. 428) and this highly mobile shelf greatly enhances the mobility of the tongue.

The transversus muscle narrows the tongue and consequently heaps up the dorsum into a side to side convexity. With simultaneous contraction of the vertical muscle this convexity is flattened and, since the total *volume* of the tongue remains constant, the organ becomes elongated and pointed at the tip. If now the lowest fibres of genioglossus contract the back of the tongue is drawn forwards, i.e. the pointed tongue is extruded.

Contraction of the longitudinal fibres shortens the tongue, which then becomes concave from front to back. Contraction of the vertical fibres produces a midline groove with consequent heaping up of the sides of the tongue, as in the first stage of swallowing.

The essential point is that the tongue volume remains constant. Therefore shortening of some fibres can only occur if others passively elongate; this results in change of shape.

It has already been pointed out that the lowest fibres of genioglossus draw the tongue forward. Styloglossus opposes this movement and retracts the organ. Hyoglossus draws the sides of the tongue downwards.

The position of the tongue is altered by the

mylohyoid muscles, on which the tongue rests. The mobile floor of the mouth can be elongated or shortened, raised or lowered, thus still further altering the position of an already mobile organ (see below).

The movements of the tongue in the *first (voluntary) stage of swallowing* illustrate its mobility. Contraction of the vertical intrinsic muscle makes a longitudinal groove on the dorsum; the heaped-up tip and edges are in contact with the hard palate and teeth. The liquid or moist bolus is thus imprisoned in the groove. Contraction of mylohyoid now raises the floor of the mouth, compressing the tongue against the hard palate. The vertical intrinsic fibres relax from before backwards; pressure from the contracting mylohyoid muscle obliterates the groove in the same sequence, forcing the bolus backwards (Fig. 6.42). It is more difficult to swallow a single bolus with the mouth open; but it is still possible. While drinking from a vessel the lips and teeth remain open and the tongue spills no liquid during swallowing. The tongue is mobile enough to perform almost any movement.

In the unconscious, the tongue muscles relax and the organ may fall backwards to obstruct the pharyngeal part of the airway; in sleep this causes snoring. Pulling the tongue forwards is an important element in restoring a patent airway in cardiopulmonary resuscitation (p. 253).

Development

Tongue muscles are derived from *suboccipital myotomes* (cranial to the first cervical segment) which migrate forwards into a sac of mucous membrane, carrying their nerve supply with them (hypoglossal nerve). The migration passes ventrally around the internal and external carotid arteries, but medial to the internal jugular vein. The epithelium (and glands) are derived from the lining of the floor of the pharynx (p. 37), and come from parts of the *first, third and fourth arches*, hence there are three sensory nerve supplies. The presulcal mucosa comes from the midline tuberculum impar and the pair of lateral lingual swellings of the first arch (lingual and chorda tympani nerves — p. 38); the postsulcal part is from the midline hypobranchial eminence of the third arch (glossopharyngeal nerve), with a small contribution from the fourth arch (internal laryngeal nerve). Tissue of the second arch is not represented because third arch tissue overgrows it in a forward direction to meet that from the first arch. The thyroid diverticulum grows downwards from the junction between the tuberculum impar and the hypobranchial eminence, the site being indicated by the foramen caecum.

Floor of the mouth

The muscles of the floor of the mouth are the two **mylohyoids** (described on p. 428) with the pair of **geniohyoids** (p. 429) lying above them adjacent to the midline anteriorly. Above the mylohyoids lies the mouth; below it lies the neck. The tongue (described above) occupies much of the floor, and below its tip and sides is the sublingual region. At the front the mucous membrane passes from side to side, covering the sublingual glands (which raise the sublingual folds) and the upper borders of the mandibular attachments of the genioglossi. At the sides the mucosa is reflected from the upper part of mylohyoid to styloglossus and hyoglossus, and covers the lingual artery as it enters the mouth below the superior constrictor.

Mylohyoid (p. 428) slopes down from the mylohyoid line of the mandible into a midline raphe; only its posterior fibres are inserted into the body of the hyoid bone. The arrangement resembles that of the levator ani in the pelvic floor. An important difference is that the raphe of the pelvic floor is attached behind to a fixed bone (the tip of the coccyx) whereas the mylohyoid raphe is attached behind to the mobile hyoid bone. The hyoid bone can be moved up and down, forwards and backwards; thus the floor of the mouth is much more mobile than the pelvic floor. This contributes a greater mobility to the already very mobile tongue.

The hyoid bone is slung between mandible and styloid process by the geniohyoid and stylohyoid muscles; their reciprocal contractions determine the anteroposterior position of the hyoid bone. Each of these muscles slopes *down* to the hyoid, as does the mylohyoid; these three muscles elevate the hyoid bone. The infrahyoid muscles depress the hyoid bone; the reciprocal contractions of these groups determine the vertical level of the hyoid bone.

Lying on mylohyoid is the mass of the tongue. Between the two are the geniohyoids near the anterior midline and laterally the hyoglossus muscle (Fig. 6.17). Hyoglossus and mylohyoid pass upwards from the hyoid bone, the former to the side of the tongue, the latter to the mylohyoid line of the mandible. The structures in the angular interval between them are shown in Figure 6.25.

The **submandibular duct** passes forwards from the superficial part of the gland (p. 436). It opens on the sublingual papilla, a low elevation on the floor of the mouth at the side of the frenulum of the tongue.

The **hypoglossal nerve** passes forwards on the lower border of hyoglossus, just above the greater horn of the hyoid bone (Fig. 6.17). At the anterior border of

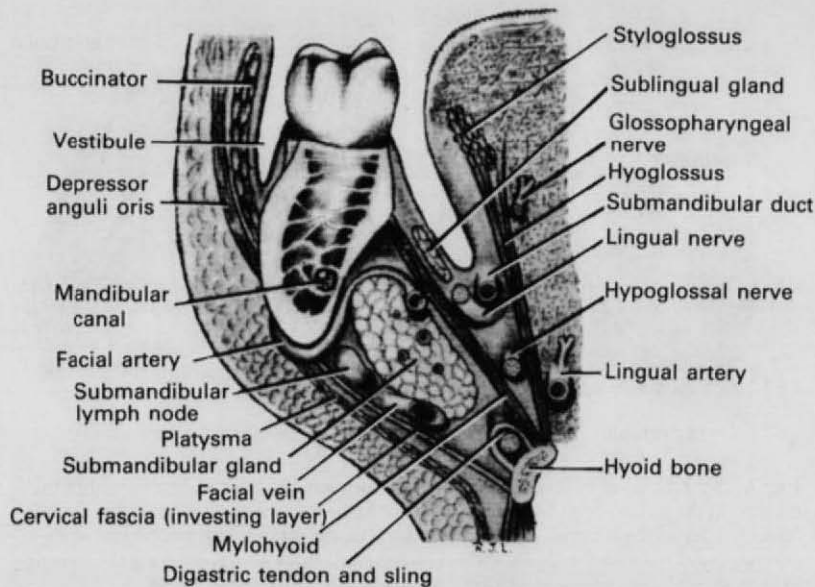


Fig. 6.25 Coronal section of the left side of the mandible and adjacent structures, just behind the first molar tooth, viewed from behind.

hyoglossus the round nerve trunk becomes flattened and breaks up into a number of branches that radiate into the muscles of the tongue. Geniohyoid receives a branch containing C1 fibres only. There is always a communication between the hypoglossal and lingual nerves, and perhaps this carries proprioceptive impulses from the muscles. The nerve is accompanied by a companion vein that drains the front of the tongue (p. 482).

The **lingual nerve** enters the mouth from outside the pharynx by passing below the inferior border of the superior constrictor at its attachment to the mandible, at the lower end of the pterygomandibular raphe (Fig. 6.26A). The nerve lies against the periosteum of the mandible at the posterior border of the third molar tooth, and runs forward on the upper surface of mylohyoid muscle (Fig. 6.26A and B). It gives off a gingival branch that runs deep to the interval between the sublingual gland and the mandible and supplies all the lingual gum and mucous membrane of the adjoining sulcus to the midline. The lingual nerve then dips under the submandibular duct and runs forward on the surface of hyoglossus above the level of the duct (Fig. 6.17). The nerve here is flattened rather than round. It is distributed to the mucous membrane of the anterior two-thirds of the tongue.

The **submandibular ganglion** hangs suspended from the lingual nerve, on the surface of hyoglossus below

the submandibular duct (Fig. 6.17). It is a relay station for the parasympathetic secretomotor fibres in the chorda tympani. Postganglionic fibres supply the sublingual and submandibular glands (with a few fibres to the submandibular gland relaying in cell bodies in the hilum of the gland). For the connexions of the ganglion see page 34.

Three structures lie deep to hyoglossus muscle (p. 482). The **lingual artery** passes deep to the posterior border of the muscle and runs forward above the greater horn of the hyoid bone (level with the hypoglossal nerve on the superficial side of the muscle) (Fig. 6.25). Dorsal branches are given off deep to the muscle and the lingual artery passes forward from beneath the anterior border of hyoglossus to reach the front of the tongue.

The **glossopharyngeal nerve** disappears beneath the upper part of hyoglossus (Fig. 6.17). It is much thinner than the hypoglossal nerve. It is distributed, like the dorsal lingual arteries, to the mucous membrane of the posterior third of the tongue and to the vallate papillae.

The **stylohyoid ligament** runs down from the tip of the styloid process to the lesser horn of the hyoid bone (Fig. 6.28). From the angle between the ligament and the greater horn the middle constrictor fibres arise (p. 487) and emerge from beneath the posterior border of hyoglossus to fan out around the pharynx.

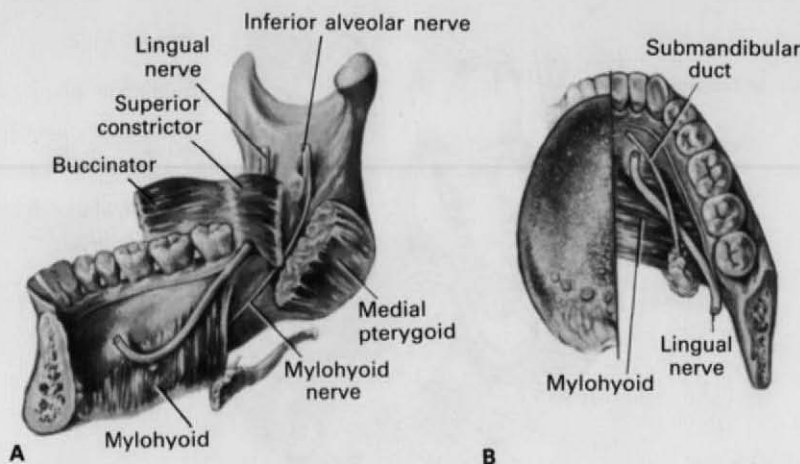


Fig. 6.26 Course of the right lingual nerve from outside the pharynx to within the mouth. In **A**, viewed from within the mouth, the nerve is seen passing under the free lower border of the superior constrictor, which interdigitates with buccinator at the pterygomandibular raphe. In **B**, the nerve is viewed from above, entering the mouth in contact with the periosteum below and behind the third molar tooth.

The **sublingual gland** is almond-shaped and lies in front of the anterior border of hyoglossus, between mylohyoid below and in front and the side of the tongue (genioglossus) medially. Laterally it lies against the sublingual fossa of the mandible (Fig. 8.14, p. 664). Its upper surface raises the sublingual fold in the floor of the mouth. At the front the two glands almost meet each other; at the back each is separated from the submandibular gland by the stylomandibular ligament. The gland is mucus-secreting (see the parotid gland for a note on structure, p. 457), and of its 15 or so ducts, half open directly into the submandibular duct, the remainder separately on the sublingual fold.

It is supplied by the lingual artery and by branches of the submental artery which pierce mylohyoid muscle to reach it. The venous return is by corresponding veins. It is innervated from the submandibular ganglion (see above).

PART 13 PHARYNX AND SOFT PALATE

PHARYNX

The **pharynx** is a fibromuscular tube applied to the *back of the face* in the same way as a respirator is applied to the front of the face. Its anterior wall is largely deficient so that it has wide communication with the nose, mouth and larynx. It extends downwards for about

12 cm (5 in) from the base of the skull to the level of C6 vertebra, where it becomes continuous with the oesophagus. Both pharynx and oesophagus are in contact posteriorly with the prevertebral fascia, which provides a foundation upon which pharynx and oesophagus can freely slide during swallowing and movements of the neck. The 'dead space' between the pharynx and the prevertebral fascia not only allows for free mobility of the pharynx and oesophagus, but also permits the extension of infection from one side to the other of the neck. It continues below into the posterior mediastinum.

Because of its anterior communications it is descriptively divided into three parts—nasal, oral and laryngeal, often known respectively as the *nasopharynx*, *oropharynx* and *laryngopharynx*, each with distinctive interior features. Its wall throughout consists of four layers which from within outwards are the mucous membrane, submucous layer (or fibrous layer), muscular layer and finally the very thin and unimportant buccopharyngeal fascia which covers the muscular layer externally.

Muscles and fascia

The muscular wall is surprisingly thin. It consists of three curved sheets of muscle, the superior, middle and inferior constrictors (supplemented by three smaller muscles: stylopharyngeus, palatopharyngeus and salpingopharyngeus). They overlap posteriorly, being telescoped into each other like three stacked cups. But

the muscle does not extend up to the base of the skull; here the immobile wall of the nasopharynx consists of a rigid membrane, the **pharyngobasilar fascia**. This is simply a dense thickening of the *submucosa* that fills in the gap between the skull and the upper border of the superior constrictor. The thickening can be traced down to the level of the soft palate, making a fourth but fibrous cup stacked inside the other three. Its stiffness keeps the nasopharynx always open for breathing, and food does not enter it. Before considering the pharyngeal musculature it is helpful to study the attachments of this fascia, after first making a general survey of the external surface of the base of the skull (p. 648).

Start from the pharyngeal tubercle, to which is attached a midline thickening, the **pharyngeal raphe**, which receives fibres from the constrictor muscles. The attachment of the fascia then passes laterally, convex forwards over *longus capitis* and the back part of the foramen lacerum to the petrous part of the temporal bone just in front of the carotid canal. From this point its attachment is to the cartilaginous part of the auditory tube, not to the skull. Below the orifice of the auditory tube it is attached to the sharp posterior border of the medial pterygoid plate, down to the hamulus. Suspended from the base of the skull, and sweeping around from one medial pterygoid plate to the other, reinforced posteriorly by the pharyngeal raphe, the pharyngobasilar fascia makes a rigid wall that holds the nasopharynx permanently open for breathing. The lower edge of the pharyngobasilar fascia lies at the site of Passavant's ridge, level with the hard palate, inside the superior constrictor muscle. The ridge (p. 494) acts like a purse-string on the lower free margin of the pharyngobasilar fascia. Below this the mucous membrane lies on a loose submucosa.

Note that the quadrangular area at the apex of the petrous bone in front of the carotid canal lies within a lateral recess of the pharynx. The levator palati muscle arises here; it is *entirely intrapharyngeal*, being covered medially by mucous membrane. Note too that the cartilaginous part of the auditory tube enters the nasopharynx above the pharyngobasilar fascia, which is firmly attached to it (Fig. 8.4, p. 646).

Superior constrictor

Examine the skull again. Note that the upper third of the posterior border of the medial pterygoid plate is more rounded and blunter to the touch than the lower part. It is rather concave, for it lodges the free end of the tubal cartilage. This border now gives way to a spur, below which the posterior border of the medial pterygoid plate is sharp to the examining finger. The

superior constrictor fibres arise below the tube, in continuity from the spur along the whole of the sharp two-thirds of the posterior border, down to and including the tip of the hamulus. The muscle fibres lie outside the pharyngobasilar fascia as they share this attachment to the edge of the medial pterygoid plate. The pharyngobasilar fascia ends at the hamulus, but the origin of the superior constrictor continues down along the pterygomandibular raphe (which runs from the hamulus to the posterior end of the mylohyoid line) to the mandible just above the attachment of the raphe, at the level of the posterior border of the last molar tooth. The superior constrictor passes backwards from the pterygomandibular raphe; buccinator passes forwards from it (Fig. 6.11).

From its origins (medial pterygoid plate, hamulus, raphe and mandible) the muscle sweeps around the pharynx, its fibres diverging mostly upwards to meet their opposite fellows at the midline pharyngeal raphe. The upper end of this raphe forms a rather prominent fibrous band which receives the uppermost constrictor fibres and is attached to the pharyngeal tubercle. The lowest fibres extend as far down as the level of the vocal folds, lying within the middle constrictor. Note that there is a space between the upper border of the superior constrictor and the base of the skull. Through here passes the cartilaginous part of the auditory tube and the rest of the space is closed by the firm pharyngobasilar fascia (Fig. 6.27).

There is a gap laterally between the superior and middle constrictors (Fig. 6.28). This is plugged by the back of the tongue and traversed by structures that pass from outside the pharynx to inside the mouth, namely stylopharyngeus (p. 489), the glossopharyngeal nerve (p. 485) and the lingual nerve (p. 485).

Middle constrictor

The stylohyoid ligament is attached to the lesser horn of the hyoid bone deep to hyoglossus. From the angle between it and the greater horn arises the middle constrictor, its fibres diverging widely as they sweep around the pharynx to end in the median raphe. The uppermost fibres reach the raphe and enclose the superior constrictor; the lower arch down as far as the level of the vocal folds. They enclose the superior constrictor and are themselves enclosed within the inferior constrictor (Fig. 6.28).

The gap between the middle and inferior constrictors is closed by the thyrohyoid membrane (p. 498), which joins the hyoid bone to the thyroid cartilage (Fig. 6.28) and walls in the laryngeal part of the pharynx at the piriform recess (p. 491). Passing through this gap by

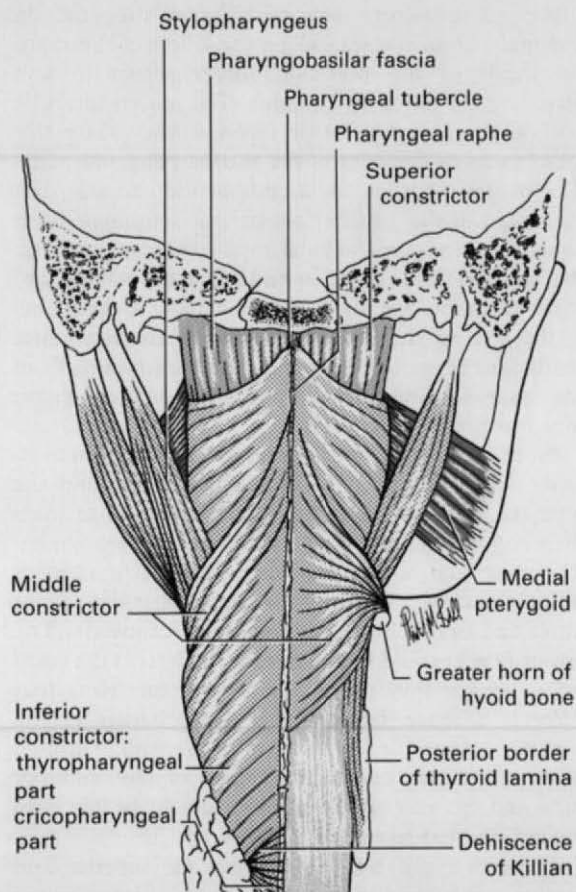


Fig. 6.27 Pharynx, from behind. On the right the inferior constrictor has been removed to show the extent of the middle constrictor and the attachment of stylopharyngeus to the posterior border of the thyroid lamina.

piercing the membrane are the internal laryngeal nerve and superior laryngeal vessels.

Inferior constrictor

This has two parts, named from their origins (Fig. 6.28). The **thyropharyngeus** part arises from the oblique line of the thyroid cartilage and in continuity below this from a fibrous arch that spans the cricothyroid muscle. It encloses the middle and superior constrictors as its fibres curve around to the midline raphe. The fibres diverge widely, sweeping up to the pharyngeal raphe with some almost reaching the pharyngeal tubercle. The lower fibres are horizontal, edge to edge with cricopharyngeus, the second part. The **cricopharyngeus**, rounded and thicker than the flat sheets of the other constrictors, extends uninter-

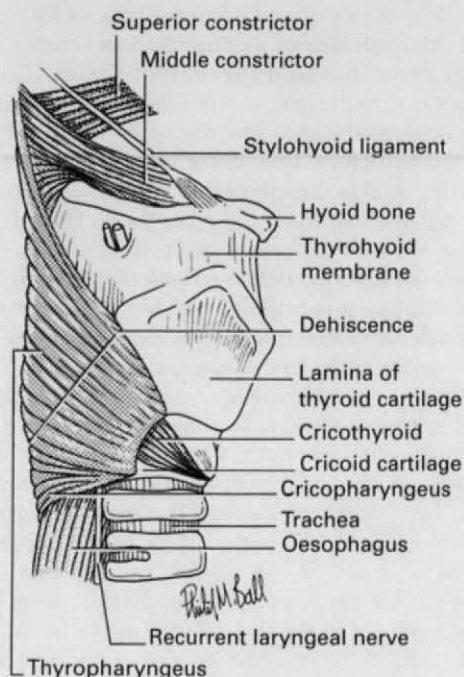


Fig. 6.28 Pharyngeal constrictors from the right.

ruptedly from one side of the cricoid arch to the other, around the pharynx. There is no raphe here. The muscle acts as a sphincter at the lower extent of the pharynx, and is continuous with the circular muscular coat of the oesophagus. It is composed largely of fibres of the 'slow twitch' variety without spindles (like the external urethral sphincter, p. 406) and is always closed, except for momentary relaxation during deglutition, and it usually has a different nerve supply from the other constrictors (see below). It imparts some resistance to the passage of an endoscope (overcome by swallowing). The closure of the cricopharyngeus prevents air from being sucked into the upper oesophagus when intrathoracic pressure falls; air is sucked only into the permanently open trachea. Passing upwards deep to the lower border of the inferior constrictor are the recurrent laryngeal nerve and inferior laryngeal vessels.

The outer surface of the pharynx is covered by the delicate epimysium of the pharyngeal constrictors. This thin tissue is continuous over the pterygomandibular raphe with the epimysium over buccinator, so it has been called the *buccopharyngeal fascia*. It is unworthy of mention except to emphasize that it must not be confused with the tough and important pharyngobasilar fascia (p. 487).

The junction between thyropharyngeus and cricopharyngeus near the midline is a potentially weak area of the pharyngeal wall, and through this area (*Killian's dehiscence*) a pouch of mucosa may become protruded (pharyngeal diverticulum). As it enlarges the pouch hangs down at the side of the oesophagus, and although it may be called an 'oesophageal' diverticulum the origin is above the cricopharyngeus. Such diverticula are normal in some species (e.g. the pig).

Palatopharyngeus

Palatopharyngeus is described with the soft palate (p. 494). Here it should be noted that from their palatal origin the muscle fibres pass down *internal* to the superior constrictor (Fig. 6.30).

Salpingopharyngeus

Salpingopharyngeus is a very slender muscle that arises from the lower part of the cartilage of the auditory tube (p. 531) and runs downwards (Fig. 6.30) to blend with palatopharyngeus.

Stylopharyngeus

Stylopharyngeus arises from the deep aspect of the styloid process high up. It slopes down across the internal carotid artery, in front of which it crosses the lower border of the superior constrictor and passes down inside the middle constrictor (Fig. 6.27). Here it lies behind palatopharyngeus and is inserted into the posterior border of the thyroid lamina and the side wall of the pharynx. The glossopharyngeal nerve curls round the posterior border of the muscle from medial to lateral, and supplies it.

Blood supply

Branches of many arteries take blood to the pharynx: ascending pharyngeal, ascending palatine, lingual, tonsillar, greater palatine, the artery of the pterygoid canal, and the superior and inferior laryngeal arteries. Venous blood is largely collected into the pharyngeal venous plexus which like the nerve plexus (see below) is situated at the back of the middle constrictor; it drains to the pterygoid plexus or directly into the internal jugular vein. From the lowest part blood finds its way to the inferior thyroid veins.

Lymph drainage

Lymph passes to retropharyngeal lymph nodes and via

these or directly to upper and lower deep cervical groups.

Nerve supply

For the *motor* nerve supply of the pharynx the general statement is that all the muscles are supplied by the *pharyngeal plexus* (see below) except for *stylopharyngeus*, which is the only muscle supplied by the *glossopharyngeal nerve*. To this must be added the qualifying statement that the cricopharyngeus part of the inferior constrictor may be supplied by the recurrent laryngeal nerve, or have an additional or even sole supply from the external laryngeal. The cell bodies that supply all six muscles on each side are in the middle part of the nucleus ambiguus, no matter by what named nerves they reach their destination. (For paralysis, see p. 642.)

The *pharyngeal plexus* lies on the posterolateral wall of the pharynx, mainly over the middle constrictor, and is formed by the union of pharyngeal branches from the vagus and glossopharyngeal nerves and the cervical sympathetic. The glossopharyngeal component is purely afferent; the pharyngeal fibres of the vagus carry some motor fibres from the cranial part of the accessory nerve as well as afferent fibres. The sympathetic element is vasoconstrictor.

The *mucosa* of the nasopharynx is supplied from the *maxillary nerve* through the pterygopalatine ganglion, whose pharyngeal branch reaches the nasopharynx via the palatovaginal canal. Most of the oropharynx receives its sensory supply from the *glossopharyngeal nerve*, but the vallecula is supplied by the *internal laryngeal nerve*, and all the rest of the pharyngeal mucosa is innervated by the *internal* and *recurrent laryngeal nerves*.

Interior of the pharynx

Just as the blank and windowless wall of a tall building gives no impression of the floors and furnishing within, so inspection of the outside of the pharynx gives no hint of its division into nasal, oral and pharyngeal parts. The interior of the nasal and oral parts is understood better after the soft palate has been studied, and the laryngeal part after considering the larynx; the description that follows should be referred to again after dealing with those structures (pp. 491 and 496).

Nasal part

This, commonly called the **nasopharynx**, extends from the base of the skull to the lower border of the soft palate (Fig. 6.21). The rigid pharyngobasilar fascia keeps it from collapsing at the back and sides. At the

front the upper part communicates with the nose through the choanae, while below this the soft palate forms its anterior wall (Fig. 6.30). The space between the lower border of the soft palate and the posterior pharyngeal wall through which the nasopharynx joins the oral part of the pharynx is the *oropharyngeal isthmus*. The soft palate becomes a mobile floor, like a trap door, when elevated during swallowing (p. 525) to meet the posterior wall, so closing the isthmus. The calibre of the nasopharynx is not large; there is no reason for it to exceed the diameter of the nostrils. The cavity equals in volume and shape the terminal segments of the owner's thumb. The main features to be noted within the nasopharynx are the pharyngeal tonsil, pharyngeal recesses and the openings of the auditory tubes.

In the mucous membrane high on the posterior wall (at the level of the basiocciput) is a collection of lymphoid nodules, prominent in children and forming the *pharyngeal tonsil* (Fig. 6.21). When enlarged the nodules are commonly known as the *adenoids*.

The *pharyngeal recess* (fossa of Rosenmüller) is a narrow vertical slit behind the opening of the auditory tube (see below), quite unlike the large bulge in the pharyngobasilar fascia visible from the outside. The recess in the fascia is almost filled by levator palati (p. 493). A catheter missing the tubal orifice and introduced into the recess may perforate the fascia and enter the internal carotid artery, which here lies against the wall of the pharynx.

The *opening of the auditory tube* lies above the soft palate in the lateral wall. The opening is guarded above, behind and in front by a prominent rounded ridge, the *torus* or *tubal elevation*, formed by the trumpet-shaped medial end of the tubal cartilage which underlies the mucous membrane, here containing lymphatic tissue, the *tubal tonsil*. At the lower margin of the opening is a very slight bulge, the *levator elevation*, due to the underlying levator palati muscle. The tubal elevation is in the shape of an inverted J, the long limb lying posteriorly and being continued downwards as the *salpingopharyngeal fold*, produced by the underlying salpingopharyngeus muscle (p. 489).

Oral part

This, the *oropharynx*, extends from the lower border of the soft palate to the upper border of the epiglottis. The wall of the oropharynx is formed posteriorly by all three constrictors. It closes completely behind a swallowed bolus, but is otherwise open for breathing. Anteriorly in front of the gap between the soft palate and epiglottis there is a mobile wall, the posterior part

of the tongue. At the sides there are projecting ridges, the *palatopharyngeal* and *palatoglossal arches* (collectively known in the old days as the *pillars of the fauces*), formed by the underlying corresponding muscles (p. 494), with the palatine tonsils between them. The palatoglossal arches form the boundary between the pharynx and the mouth. The features of interest in the oropharynx are the palatine and lingual tonsils and the valleculae.

The *palatine tonsil* (the pair commonly called simply 'the tonsils') is a large collection of lymphoid tissue which projects into the oropharynx from the *tonsillar fossa*, the arrow-shaped area between the palatopharyngeal fold behind and the palatoglossal fold in front. The floor of the fossa (the bed of the tonsil) is the lower part of the superior constrictor, probably overlain by some palatopharyngeus fibres. The glossopharyngeal nerve crosses the lower part of the bed, running obliquely downwards and forwards to reach the tongue by passing under the lower border of the constrictor.

The tonsil can be described as having borders, poles and surfaces. The *anterior* and *posterior borders* lie adjacent to the palatoglossal and palatopharyngeal folds respectively. The *upper pole* extends to the soft palate and may even infiltrate it; the *lower pole* reaches the dorsum of the tongue. The *medial surface* projects to a variable degree and is covered by pharyngeal mucosa which shows on its surface the openings of up to 20 *tonsillar crypts*—epithelial downgrowths. One large downgrowth near the upper pole is the *intratonsillar cleft* (often wrongly called *supratonsillar*; it is *not above* the tonsil but *within* it); it is the remains of the embryonic second pharyngeal cleft. The *lateral surface*, on the tonsillar bed, is covered by thickened pharyngeal submucosa that forms the tonsillar capsule, an extension of the pharyngobasilar fascia. (A peritonsillar abscess occurs outside the capsule.) The superior constrictor separates this surface from the facial artery and two of its branches, the ascending palatine and tonsillar. A small semilunar fold of mucosa separates the tonsil from the uvula and extends from the palatopharyngeal arch to the upper pole. (A second mucosal fold, from the palatoglossal arch extending over the lower part, is present in fetal life, but disappears in childhood because it becomes invaded by tonsillar tissue.) The palatine, lingual, pharyngeal and tubal tonsils collectively form an interrupted circle of lymphoid tissue (*Waldeyer's ring*) at the upper end of the respiratory and alimentary tracts.

Blood supply. The tonsillar branch of the facial artery forms the main arterial supply; it enters the tonsil by arching over the upper border of styloglossus and piercing the superior constrictor. There are smaller

contributions from the lingual, ascending pharyngeal and ascending palatine vessels. The internal carotid artery is about 2.5 cm (1 in) posterolateral to the tonsil and separated from the pharyngeal wall by loose fat and connective tissue. It is therefore well out of the way in tonsillectomy (although an unusually tortuous internal carotid has been known to be damaged).

The veins form a plexus round the capsule and pierce the superior constrictor to drain into the pharyngeal plexus. One particularly large vein comes into the tonsillar bed from the soft palate; this is the external palatine vein, commonly called *paratonsillar*, and the one usually causing venous haemorrhage after tonsillectomy.

Lymph drainage. Lymphatic channels pierce the superior constrictor to reach nodes of the deep cervical group, mostly to the jugulodigastric nodes below the angle of the mandible.

Nerve supply. The mucous membrane overlying the tonsil is supplied by the tonsillar branch of the glossopharyngeal nerve and the lesser palatine nerves (p. 469).

Tonsillectomy. The older method of removing tonsils by guillotine has given place to a more precise approach. The tonsil is dissected away from the tonsillar bed by cutting through the mucous membrane at the margins of the arches, starting at the upper pole and working down and keeping close to the tonsillar capsule. Undue haemorrhage may arise from the paratonsillar vein; arterial haemorrhage should only be a hazard if the tonsillar bed has been penetrated—the tonsillar and ascending palatine arteries (and rarely an unusually tortuous facial artery) lie on the outer side of the superior constrictor. The internal carotid artery should be more than 2 cm away, but even this has been known to curl to the pharyngeal wall and be damaged. The glossopharyngeal nerve is at risk if the lower part of the superior constrictor is penetrated.

The **valleculae** lie between the epiglottis and the posterior surface of the tongue. They are shallow pits separated by the median glossoepiglottic fold and limited inferolaterally by the lateral glossoepiglottic folds. The nerve supply of the mucosa of the valleculae, including that of the very lowest part of the tongue that forms the anterior vallicular wall (p. 481), is by the internal laryngeal nerve. A crumb that 'goes down the wrong way' is one that lodges in the vallecula and sets up a reflex bout of coughing (p. 503) to dislodge it.

Laryngeal part

This part of the pharynx, the **laryngopharynx**, extends from the upper border of the epiglottis to the

level of the cricoid cartilage (C6 vertebra) where it becomes continuous with the oesophagus. Its main features are the opening into the larynx (*aditus or laryngeal inlet*) which bulges backwards into the third part of the pharynx, and the piriform recesses on either side. The posterior wall is formed by the three overlapping constrictors down to the level of the vocal folds (upper border of cricoid lamina). Below this (i.e. behind the cricoid lamina) is the dehiscence of Killian and finally the cricopharyngeal sphincter. At each side of the epiglottis the *lateral glossoepiglottic fold* separates the oropharynx from the laryngeal part. Below the fold is the **piriform recess** (piriform fossa). This is bounded medially by the quadrangular membrane of the larynx, below the aryepiglottic fold (p. 498). The lateral wall of the recess, beneath the mucous membrane, consists of thyrohyoid membrane above and the lamina of the thyroid cartilage below (Fig. 6.29). The recesses are danger sites for perforation by an endoscope.

The piriform recesses, broad above and narrow below, lie beside the aperture of the larynx. Below the aperture the arytenoids and the lamina of the cricoid cartilage are draped over with mucous membrane. This lower part of the pharynx (often called by clinicians the **hypopharynx**) thus possesses an anterior wall. It is flat, and the posterior wall lies against it, obliterating the piriform recesses as the hypopharynx tapers off, wedge-shaped, into the clasp of the cricopharyngeus muscle. Note that the posterior wall of the hypopharynx is, in fact, the dehiscence of Killian.

The thyrohyoid membrane is perforated by the *superior laryngeal vessels* and the *internal laryngeal nerve*. Note that when these vessels and nerve perforate the thyrohyoid membrane they are not yet in the larynx, but lie beneath the mucous membrane of the piriform recess. Similarly the *inferior laryngeal vessels* and *recurrent laryngeal nerve*, passing beneath the cricopharyngeus part of the inferior constrictor, enter first the pharynx. The superior and inferior vessels anastomose and the nerves communicate in the mucous membrane of the pharynx, which they supply (Fig. 6.29). After having given off these communicating branches the vessels and nerves enter the larynx. In the larynx they have no anastomoses; the vocal folds are a complete watershed for vessels and nerves.

SOFT PALATE

The **soft palate** hangs down from the back of the hard palate as a mobile fold that fuses at the sides with the lateral wall of the pharynx and which can be raised so that its lower border makes contact with the posterior wall of the pharynx to close off the nasopharynx during

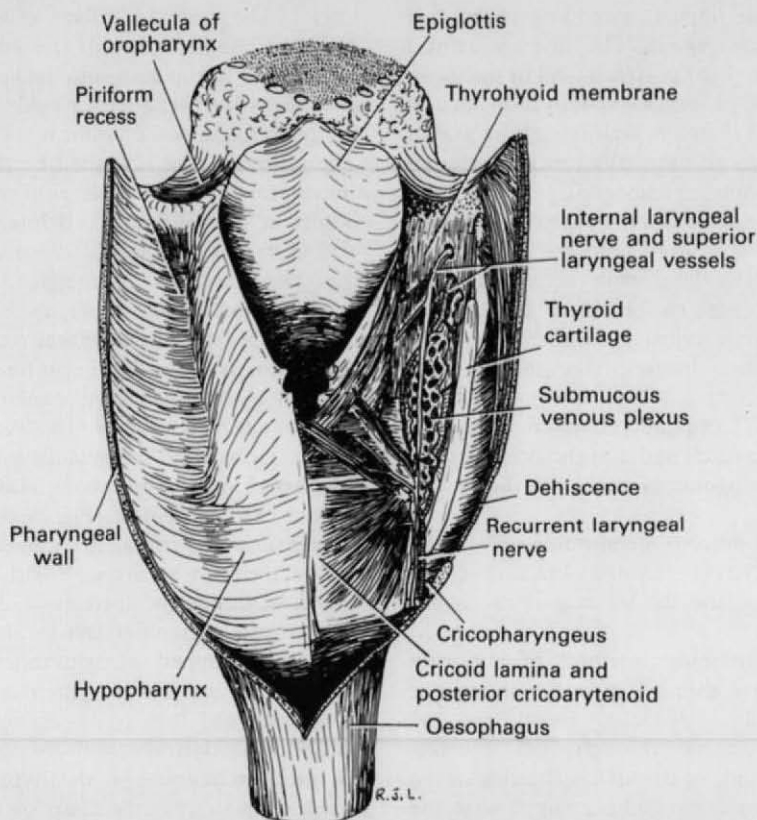


Fig. 6.29 Laryngeal part of the pharynx from behind. On the right the mucous membrane has been removed to show the anastomoses within the pharynx of the superior and inferior laryngeal vessels and of the internal and recurrent laryngeal nerves. There is no such overlap in the larynx; the vocal folds are a complete 'watershed'.

swallowing. It consists of an **aponeurosis** that is acted upon by several muscles to alter its shape and position, but much of its bulk is due to the large volume of mucous and serous glands within the mucous membrane of its oral surface. There are five paired **muscles**: tensor palati, levator palati, palatoglossus (which also belongs to the tongue), palatopharyngeus (which also belongs to the pharynx) and the muscle of the uvula. The tensor and levator are properly called tensor veli palatini and levator veli palatini, but the older and simpler name is retained here.

Tensor palati

This is a thin *triangular* muscle. It arises outside the palate from the scaphoid fossa at the upper end of the medial pterygoid plate, the lateral side of the cartilaginous part of the auditory tube, and the spine of the

sphenoid, i.e. from a bony origin at the front and back and from cartilage in between. From this origin of about 2 cm in extent the flat muscle converges towards the base of the pterygoid hamulus where it becomes a flat tendon. The tendon passes above the fibrous arch in the origin of the buccinator (Fig. 6.11), bends at a right angle around the hamulus and so gets inside the pharynx. The tendon now broadens out into a wide triangular *aponeurosis*. Its anterior border is attached to the crest of the palatine bone, the medial border blending with that of the opposite side. The posterolateral border blends with the side wall of the pharynx in front, but hangs free behind, forming the edge of the soft palate with the dependent uvula in the midline. In *cleft palate* the muscle is abnormally inserted into the back of the hard palate. The **uvula** is a mass of mucous glandular tissue, with some unimportant muscle fibres attached to the posterior nasal spine. Note that each

tensor palati consists of two triangles converging on the base of the hamulus, the vertical one of muscle, the other of aponeurosis. The aponeurosis is not flat, but concave towards the mouth; when tensed by contraction of the muscle it is flattened and therefore depressed somewhat. The main action of the tensor palati is so to tense the palatine aponeurosis that other muscles may elevate and depress it without altering its shape. When the tensor palati contracts (e.g. in swallowing) it pulls upon the cartilage of the auditory tube, opens the tube, and permits equalization of air pressure between the middle ear and nose (Fig. 6.30).

Levator palati

This is a *round* mass of muscle about as thick as a pencil. Arising from the quadrate area at the apex of the

petrous bone anterior to the carotid canal and from the adjacent medial side of the cartilaginous part of the auditory tube, it forms a rounded belly that is inserted into the nasal surface of the palatine aponeurosis between the two heads of palatopharyngeus. The two levator muscles in passing down to the palate are directed forwards and medially, together forming a V-shaped sling (Fig. 6.32). Their contraction pulls the palate upwards and backwards. If the tensor is relaxed two dimples appear on the oral surface of the palate as the levators contract; much more usually the tensor stiffens the palatine aponeurosis and the soft palate is raised without alteration in shape. In either case the nasopharynx is shut off from the oropharynx by the action of the levators. The soft palate comes into contact with the posterior wall of the pharynx at Passavant's ridge (see below) on a level with the

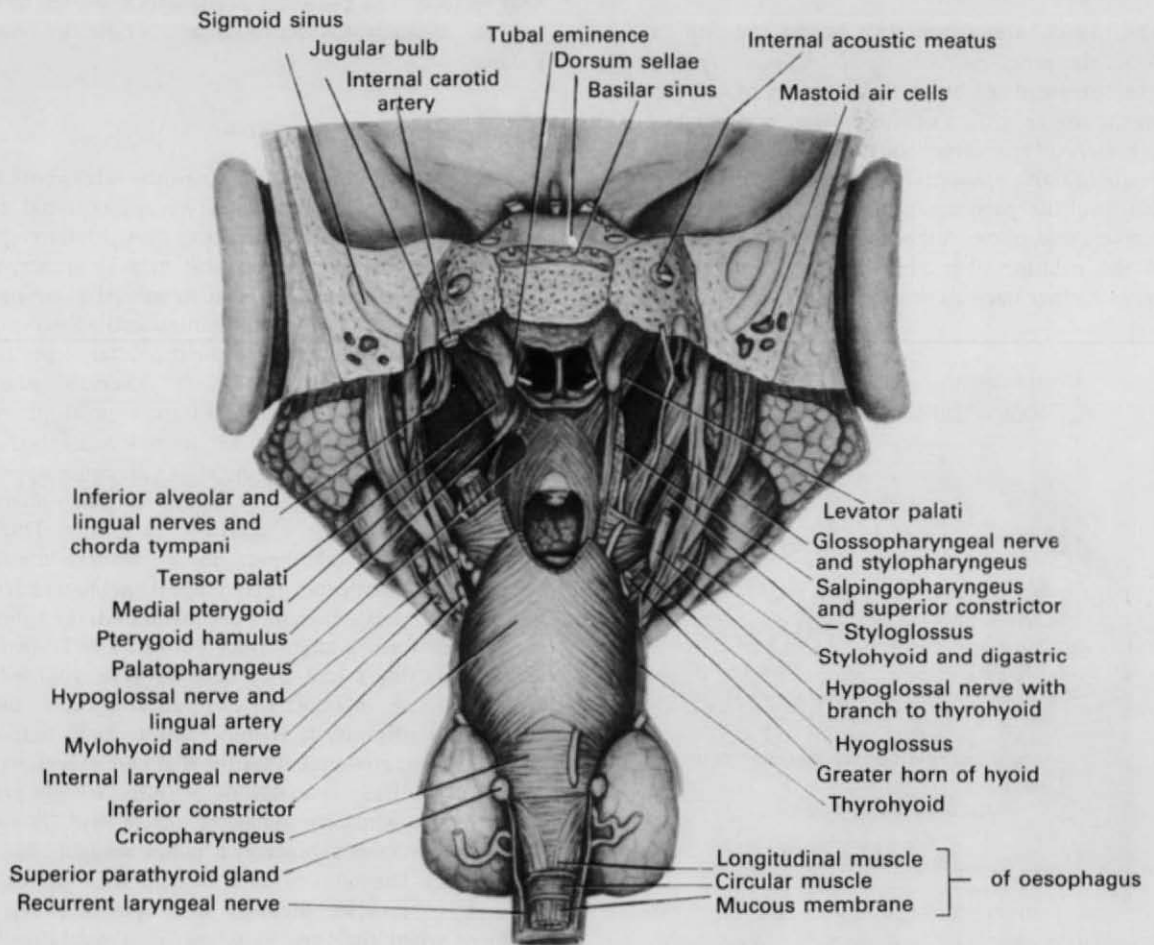


Fig. 6.30 Pharynx from behind with the nasopharynx opened to show the soft palate musculature.

anterior arch of the atlas vertebra. Contraction of the levator also opens the cartilaginous tube and equalizes air pressure between the middle ear and the nose.

Palatoglossus

The muscle arises from the under surface of the palatine aponeurosis and passes downwards to interdigitate with styloglossus. The muscle raises the *palatoglossal fold* of mucous membrane in front of the tonsil (the anterior pillar of the fauces), marking the junction between mouth and pharynx, and between mucous membrane supplied by mandibular and glossopharyngeal nerves. Its action is sphincteric at the oropharyngeal isthmus; it raises the tongue and narrows the transverse diameter of the isthmus.

Palatopharyngeus

The muscle arises from two heads, the one fixed to bone, the other movable on the palatine aponeurosis. The two heads embrace the insertion of levator palati on the upper surface of the palatine aponeurosis. The *anterior head* arises from the posterior border of the hard palate (i.e. the horizontal plate of the palatine bone). At this level the palatine aponeurosis lies just on its oral surface, and passes further forwards to reach the crest of the palatine bone (Fig. 6.31). The *posterior head* arises further back on the upper surface of the aponeurosis

(Fig. 6.30). The two heads arch downwards over the lateral edge of the aponeurosis, join, and form a muscle that passes downwards beneath the mucous membrane and submucosa of the lateral wall of the pharynx just behind and lateral to the tonsil. In the pharyngeal wall it is *the most internal of all the muscles*. The upper part of the muscle raises the palatopharyngeal fold of mucous membrane that constitutes the posterior pillar of the fauces; the lower part is inserted chiefly into the posterior border of the thyroid lamina and its horns; the muscle ought rightly to be named palatolaryngeus. Some of the anterior fibres are inserted into the upper border of the thyroid lamina just in front of the superior horn. Some of the posterior ones merge with the surrounding fibres of the inferior constrictor.

The anterior head is fixed to bone; this part of the muscle is an elevator of the larynx and pharynx. It arches the relaxed palate, making it more concave on its oral surface. The posterior head, attached only to the palatine aponeurosis, depresses as a whole the tensed palate.

Palatopharyngeal sphincter

In keen-scented mammals the epiglottis rides above the level of the soft palate and the larynx is intranarial. It is supported in this elevated position by stylopharyngeus and salpingopharyngeus and held in a sphincter, the palatopharyngeus muscle, that clasps the laryngeal inlet. In man the larynx is never intranarial: at its much lower level it has pulled down the sphincter to produce the palatopharyngeus muscle as described above. However, some fibres remain to form a 'palatopharyngeal sphincter' (Figs 6.31–6.33) at the level of the hard palate and anterior arch of the atlas (though it appears uncertain whether the fibres belong to palatopharyngeus or the superior constrictor or both). During swallowing they take part in a general forward movement of the posterior pharyngeal wall to which the elevated soft palate becomes approximated; the sphincteric fibres form a slight ridge (historically known as *Passavant's ridge*), and they become hypertrophied in cleft palate, in an effort to close an abnormally large pharyngeal isthmus. It is important to note that the ridge is not an anatomical feature that can be seen when inspecting a living or cadaveric pharynx; it only exists momentarily when the palate is raised, and (like the lower oesophageal sphincter) it is not recognizable on dissection. The illustrations of sphincter fibres in Figures 6.31–6.33 indicate their position at the moment when they are in action. It is palatal rather than pharyngeal movement that is mainly responsible for closing off the nasopharynx from the oropharynx.

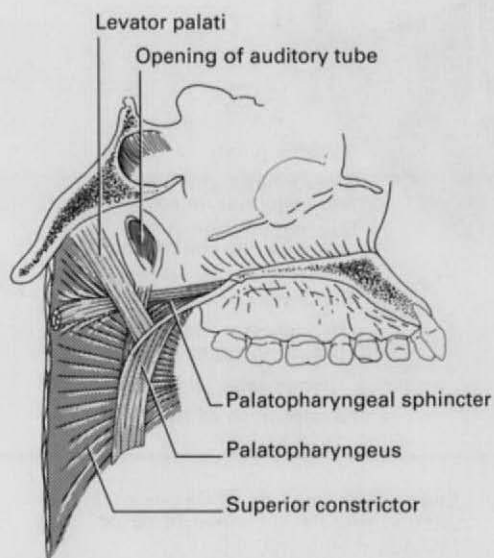


Fig. 6.31 Muscles of the left side of the palate, viewed from the right (medial) side. See text for an explanation of the sphincter fibres shown here and in Figures 6.32 and 6.33.

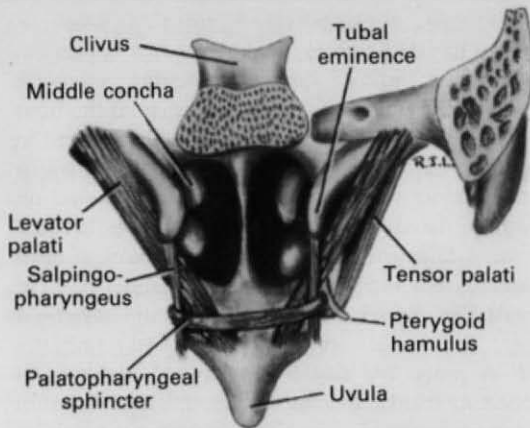


Fig. 6.32 Muscles of the nasopharyngeal isthmus from behind.

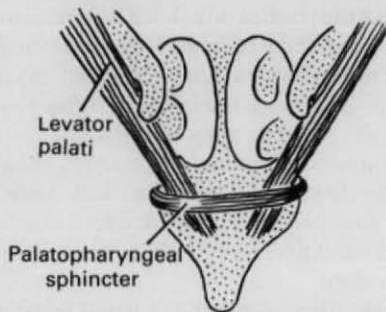


Fig. 6.33 Palatal elevation: the V of the levators is imprisoned in the V of sphincter fibres. The elevated soft palate thus seals the nasopharyngeal isthmus.

Blood supply

Lesser palatine branches of the maxillary artery, the ascending palatine branch of the facial artery, and palatine branches of the ascending pharyngeal artery anastomose freely in the soft palate. Most of the venous blood is drained laterally through the wall of the pharynx into the pharyngeal venous plexus and the pterygoid plexus.

Lymph drainage

By lymphatics that empty into the retropharyngeal and upper deep cervical lymph nodes.

Nerve supply

The general statement is that all the muscles of the soft palate are supplied by the *pharyngeal plexus* except for

tensor palati, which is supplied by a branch from the nerve to the *medial pterygoid* (from the mandibular branch of the trigeminal nerve—p. 461). The plexus fibres to the palate are from the nucleus ambiguus via the cranial part of the accessory nerve and the pharyngeal branch of the vagus. Secretomotor fibres to the palatal glands run with the lesser palatine nerves and are derived from cell bodies in the pterygopalatine ganglion. They are activated from the superior salivary nucleus in the pons by way of the nervus intermedius and the greater petrosal nerve (p. 571).

The mucous membrane of the soft palate is supplied essentially from the *maxillary* division of the trigeminal nerve, though on its oral surface there is an overlap of *glossopharyngeal* fibres that encroach on its lateral border from the lateral wall of the pharynx. Maxillary nerve fibres are derived from the (usually) paired lesser palatine nerves which pass through the pterygopalatine ganglion without relay, their cell bodies lying in the trigeminal ganglion. Taste fibres in the greater petrosal nerve supply the few taste buds on the oral surface of the soft palate (cell bodies in the geniculate ganglion, central processes in the nervus intermedius and so to the tractus solitarius in the pons). The greater petrosal nerve carries a few trespassing fibres of common sensation from the facial nerve; these run in the lesser palatine nerves to the intratonsillar cleft (p. 490). Their cell bodies are in the geniculate ganglion.

Structure

The soft palate is covered with 'wear and tear' epithelium (stratified squamous) on its oral surface and on the posterior part of its nasal surface, where it comes into contact with Passavant's ridge. Its oral epithelium contains a few scattered taste buds. The anterior part of its nasal surface is covered with respiratory mucous membrane. The thickness of the palate and uvula is occupied by a large mass of mucous and serous glands below the palatine aponeurosis; the ducts of these glands open by orifices scattered over the oral epithelium. Scattered lymphatic follicles are found in the oral mucous membrane.

Movements and function

The soft palate is a flap-valve that can shut off the oropharynx from the mouth (e.g. during chewing, so that breathing is unimpeded) or from the nasopharynx (e.g. in swallowing to prevent food entering the nasopharynx, or in coughing when the whole blast escapes through the mouth, or when blowing the bugle, etc.). When elevated it locks into Passavant's ridge,

which exists only at this moment and disappears as the soft palate comes down. The plentiful mucous glands make its oral surface slippery, like the posterior third of the tongue, for swallowing. Short of full upward or downward closure, its position is determined by the opposing pulls of levator palati and the posterior head of palatopharyngeus; thus can the resonating chambers be altered to modify the quality of the voice. In sneezing, it is held firm to resist being blown inside-out and its position determines how much of the blast is directed through the nose. Too violent an explosion might damage the conchae; the excess escapes harmlessly through the mouth.

If there were no crossing of air and food pathways there would be no soft palate. The crossing is beneficial in several ways. The nose must be narrow for warming, moistening and cleaning the gentle stream of air in tranquil breathing. It is inadequate for increased pulmonary ventilation; the open mouth is needed then. Coughing would be very ineffective if sputum had to be expelled through the narrow nose instead of into the pharynx or mouth, to be expectorated or swallowed. And you cannot talk through your nose (try it with closed lips).

Elevation of the palate and contraction of pharyngeal muscles—the **gag reflex**—occur when the palate, tonsil, posterior part of the tongue or posterior pharyngeal wall are touched by an unfamiliar object, as when testing with a swab (but the passage of food over the same areas does not cause the reflex, due to conditioned familiarity). The afferent side of the reflex is glossopharyngeal to the nucleus of the tractus solitarius and the efferent is vagal.

PART 14

LARYNX

The **larynx** is a respiratory organ, set in the respiratory tract between the pharynx and trachea. It lies below the hyoid bone in the midline of the neck where the laryngeal prominence, commonly known as Adam's apple, is the most obvious part. It projects backwards into the laryngeal part of the pharynx where the inlet of the larynx is situated. The larynx becomes continuous with the trachea at the level of C6 vertebra.

Comparative anatomy

The essential reason for the existence of a larynx is not for *phonation*, although this has become a major

function in man, but to provide a *protective sphincter* at the inlet of the air passages. The larynx first appears in the lung fish as a simple muscular sphincter surrounding the opening of the air passage in the floor of the pharynx. A functional improvement is found in the addition of dilator fibres which radiate outwards from the sphincter. Next a bar of cartilage appears on each side of the larynx; to it the dilator fibres become attached. A later modification is the division of each cartilaginous bar into a cranial and a caudal half. In mammals the cranial halves appear as the arytenoid cartilages; the caudal cartilages fuse to form a ring, the cricoid. A protective shield, the thyroid cartilage, is developed anteriorly. Evidence of the essential function of the larynx is provided by birds, in whom the rima of the glottis (the space between the vocal folds) in the floor of the mouth shuts to close the air inlet, but is silent; phonation is from a dilatation, the *syrinx*, at the lower end of the trachea just above its bifurcation.

Keen-scented animals, in order not to interrupt respiration during swallowing, have developed an intralaryngeal larynx. The epiglottis has evolved as a flap to protrude above the soft palate in these animals. The inlet of the larynx, protruding into the nasopharynx, is suspended there by the elevators of the larynx, and clasped by the sphincter muscle of the pharyngeal isthmus. The epiglottis is a modification for olfaction in these animals (but not in man).

In animals that possess an intralaryngeal larynx and also have to swallow large amounts of liquid food (e.g. ruminants, toothed whales, etc.) there are developed folds of mucous membrane that form side-walls rising above the glottis. A lateral gutter thus passes along each side of the epiglottis and laryngeal aperture—a food channel for deglutition during uninterrupted respiration. The aryepiglottic folds are a modification for deglutition.

SKELETON OF THE LARYNX

The skeletal framework of the larynx consists of cartilages, joints, ligaments and membranes. There are three single cartilages (thyroid, cricoid and epiglottic) and three pairs of cartilages (arytenoid, corniculate and cuneiform) and also three pairs of joints (cricothyroid, cricoarytenoid and arytenocorniculate). The ligaments and membranes can be classified as extrinsic (thyrohyoid membrane and cricotracheal, hyoepiglottic and thyroepiglottic ligaments) and intrinsic (quadrangular membrane and cricothyroid ligament). The all-important vocal folds (vocal cords) are formed from the upper part of the cricothyroid ligament (cricovocal membrane).

Cartilages

The thyroid, cricoid and arytenoid cartilages are composed of hyaline cartilage; with age, parts of them may calcify or ossify. The epiglottic, corniculate and cuneiforms are of elastic fibrocartilage.

The **thyroid cartilage** (Fig. 6.34) consists of two conjoined *laminae* whose posterior borders are free and projected upwards and downwards as the *superior* and *inferior horns*. Each inferior horn articulates with the cricoid cartilage to form the cricothyroid joint. The outer surface of each lamina possesses an oblique ridge bounded above and below by a tubercle. The site of union of the two laminae anteriorly forms the **laryngeal prominence** (Adam's apple). A deep midline notch lies above the prominence.

The **cricoid cartilage** is the foundation of the larynx; to this signet-ring structure (Fig. 6.35) the thyroid and arytenoid cartilages are articulated by synovial joints. It is the only complete cartilaginous ring in the whole of the air passages. The anterior part of the ring is the *arch*; posteriorly it is projected upwards as a quadrangular flat part, the *lamina*. Near the junction of the arch and lamina is an articular facet for the inferior horn of the thyroid cartilage. Note that the upper part of the lamina has sloping shoulders, which carry articular facets for the arytenoids. A vertical ridge in the midline of the lamina produces a shallow concavity on each side for the attachment of the posterior cricoarytenoid muscle; the ridge itself gives attachment to the oesophageal tendon.

The **epiglottic cartilage** is a slightly curled, leaf-shaped structure, prolonged below into a slender process (the stalk of the leaf) attached in the midline to the thyroid cartilage below the notch in its upper border. The epiglottic cartilage leans back from its

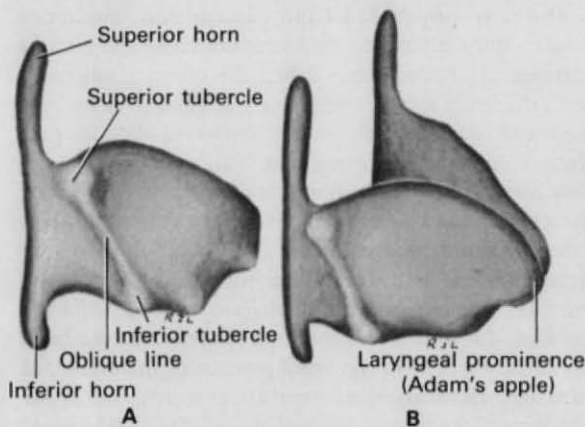


Fig. 6.34 Thyroid cartilage, **A** from the right, **B** from the right and above and slightly in front.

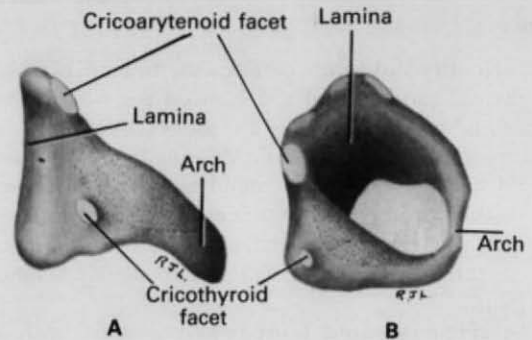


Fig. 6.35 Cricoid cartilage, **A** from the right, **B** from the right, above and in front.

attached stalk to overhang the vestibule of the larynx. The prominence on the posterior surface below the apex, the 'cushion' of the epiglottis, is produced by the shape of the cartilage, enhanced by an overlying collection of mucous glands.

The **arytenoid cartilages** articulate with the upper border of the lamina of the cricoid, and give attachment to the vocal folds and various laryngeal muscles. Each has the shape of a gracefully curved pyramid (Fig. 6.36), with at the base a forward projection (the *vocal process*) attached to the vocal fold, and a lateral projection (the *muscular process*) for the cricoarytenoid muscles. The *superior process* of the arytenoid articulates with the very small and nodular *corniculate cartilage* to which is attached the aryepiglottic fold. A little more anteriorly the tiny *cuneiform cartilage* lies within the aryepiglottic fold. The inferior surface of each arytenoid articulates with a sloping shoulder on the upper border of the cricoid lamina to form the cricoarytenoid joint.

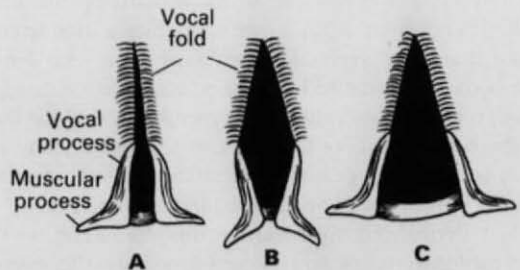


Fig. 6.36 Movements of the arytenoid cartilages. In **A**, the vocal folds are adducted. In **B**, rotation of the arytenoids, as in animals, produces a diamond-shaped opening. In **C**, lateral excursion of the arytenoids produces the human V-shaped opening.

Joints

The **cricothyroid joint**, between the inferior horn of the thyroid cartilage and the facet on the side of the cricoid, is synovial. There is a capsule reinforced by a thickening below and behind. Movement between the cricoid and thyroid occurs round an axis that passes transversely between the two joints, so that one cartilage can rock backwards and forwards on the other. The recurrent laryngeal nerve lies immediately behind this joint.

The **cricoarytenoid joint** is also synovial, with a capsule reinforced by the posterior cricoarytenoid ligament. The capsule is lax, allowing both rotary and lateral gliding movements. The ratio of rotary to gliding movements varies widely in different species. Gliding of the arytenoids opens the gap between the vocal folds (the rima of the glottis) in the shape of a V; rotation opens it in the shape of a diamond. When the arytenoids are pulled laterally and downwards they slide apart from one another along the sloping shoulders of the cricoid lamina; because of the geometry of joint surfaces, which are slightly saddle-shaped, the lateral movement is accompanied by a small amount of rotation. In man there is a greater range of gliding than of rotary movement, and the open human glottis resembles a V and not a diamond (Fig. 6.36).

The very small *arytenocorniculate joints* (either synovial or fibrous) are of no significance.

Ligaments and membranes

Of the *extrinsic membranes*, the **thyrohyoid membrane** connects the whole length of the upper border of the thyroid laminae and superior horns to the body and greater horns of the hyoid bone (Fig. 6.37). The midline part is thickened as the *median thyrohyoid ligament*, and the posterior free borders form the *lateral thyrohyoid ligaments*, each of which contains the small and unimportant *triticeal cartilage* (like a rice grain). Note that the thyrohyoid membrane passes up *behind* the body of the hyoid bone to be attached to its *upper* border; a bursa lies between the membrane and the back of the bone. It is here that remnants of the thyroglossal duct (p. 39) may persist, necessitating resection of the central part of the bone to give adequate removal.

The thyrohyoid membrane forms the lateral wall of the piriform recess and is perforated by the *internal laryngeal nerve* and *superior laryngeal vessels*. It is not part of the larynx, but anchors the skeleton of the larynx to the hyoid bone.

The epiglottis is connected to the sides of the arytenoid cartilages by the *aryepiglottic folds* of mucous

membrane, to the tongue by the *median glossoepiglottic fold*, and to the pharynx by the *lateral glossoepiglottic folds*. The epiglottic cartilage is attached to the hyoid bone and thyroid cartilage by the *hyoepiglottic* and *thyroepiglottic ligaments*. The former consists of rather loose fibroelastic tissue connecting the anterior surface of the cartilage to the upper border of the hyoid. The latter is a much denser band attaching the stalk of the cartilage to the angle between the thyroid laminae just below the thyroid notch.

The *cricotracheal ligament* is the name given to the tissue that connects the lower border of the cricoid cartilage to the first cartilaginous ring of the trachea.

Of the *intrinsic membranes*, the **quadrangular membrane** (Fig. 6.37) extends between the arytenoid cartilage and the epiglottis and is a thin fibroelastic membrane. Its anterior border is attached to the side of the lower half of the epiglottis. Its posterior border, much shorter, is attached between the vocal process of the arytenoid and the corniculate cartilage. Its lower border is free, constituting the **vestibular fold**, formerly known as the 'false vocal cord'. Its upper border, much longer than the false cord, constitutes the **aryepiglottic fold**, at the inlet of the larynx. The aryepiglottic fold contains the tiny cuneiform cartilage.

In shape the quadrangular membrane resembles the mainsail of a boat. The two aryepiglottic folds make together an oval **inlet of the larynx** that lies in a vertical plane, with the upper half of the epiglottis projecting free above. The shape of the larynx, from the vertical aperture between the aryepiglottic folds down to the horizontal lower border of the cricoid cartilage, can be compared with an old-fashioned ventilator on a ship's deck.

The other intrinsic membrane is the **cricothyroid ligament**. The midline part (*median cricothyroid ligament*) is a thickened band passing from the upper border of the cricoid to the lower border of the thyroid cartilage (and sometimes called the *conus elasticus*, a term that may also be confusingly applied to the whole ligament). The much more important lateral part (*lateral cricothyroid ligament* or *triangular membrane*), containing many elastic fibres, is often and better called the **cricovocal membrane** (Fig. 6.37A), and projects upwards from the arch of the cricoid cartilage. At the front it becomes attached (adjacent to its fellow) at the junction of the laminae of the thyroid cartilage, midway between the notch and the lower border. At the back the attachment is to the vocal process of the arytenoid cartilage. Between these two attachments the upper border is free and thickened as the **cricovocal ligament**; covered by mucous membrane, it forms the **vocal fold** (vocal cord). Thus, although the cricovocal

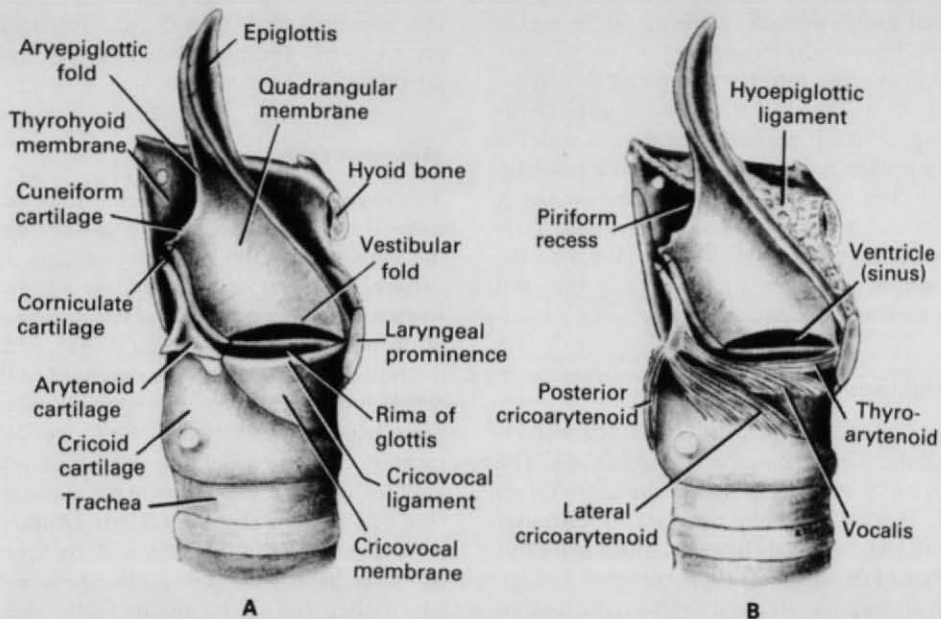


Fig. 6.37 Skeleton of the larynx. **A** Interior, viewed from the right with the right quadrangular membrane and the right halves of the thyroid cartilage and hyoid bone removed. **B** Similar view showing muscles attached to the right arytenoid cartilage.

membrane of each side has a semicircular base (on the cricoid cartilage), the upper border is straight and forms part of the V-shaped gap, the glottis (see below).

CAVITY OF THE LARYNX

The **inlet** (aditus) of the larynx, through which it communicates with the pharynx, faces backwards and upwards and is bounded in front by the upper edge of the epiglottis, at the sides and back by the aryepiglottic folds, and in the posterior midline by the interarytenoid fissure (Fig. 6.38). The space below the level of the inlet down as far as the vestibular folds is the **vestibule**, whose lower boundary (between the vestibular folds of each side) is the *rima of the vestibule*. The space between the vestibular and vocal folds that indents the lateral wall forming a deep horizontal groove is the **ventricle** of the larynx (but sometimes called the *laryngeal sinus*) (Fig. 6.37A). Opening from its anterior end is a small pouch of mucous membrane, the *laryngeal saccule*, which extends upwards for a few millimetres between the vestibular fold and the thyroid lamina.

The all-important part of the laryngeal cavity is the **rima of the glottis** (or simply 'the glottis'), the antero-posterior slit through which air passes (Fig. 6.36). The anterior 60% of the glottis (*intermembranous part*) is bounded on each side by the vocal fold (see above).

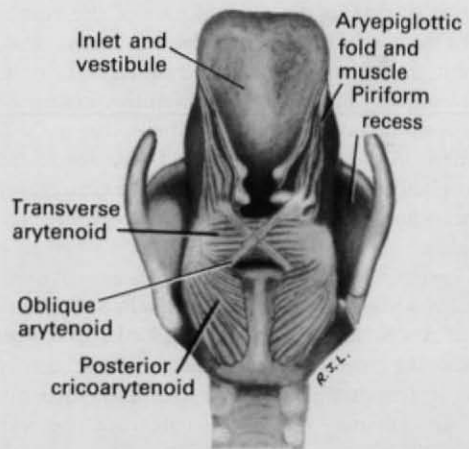


Fig. 6.38 Larynx from behind after removal of the mucous membrane.

The posterior 40% of each side (*intercartilaginous part*) is formed by the vocal process of the arytenoid cartilage (covered of course by mucous membrane), while at the back are the bases of those cartilages. In the resting state during quiet respiration, the gap between the folds is triangular and about 8 mm wide at the back, where the vocal processes of the arytenoids are parallel to each

other; the total length of each side is about 23 mm in the male and 17 mm in the female.

Below the glottis the infraglottic part of the larynx extends down to the level of the lower border of the cricoid cartilage where it becomes continuous with the trachea. Do not confuse the rima of the vestibule with the rima of the glottis. On looking down into the larynx from above, as with a laryngoscope, the vestibular folds appear as bulges of mucosa above and lateral to the vocal folds, which are lower and closer together and move with respiration and phonation.

Mucous membrane

As part of the respiratory tract, the larynx in general is lined by *pseudostratified columnar ciliated epithelium*. The anterior surface of the epiglottis (not in the larynx) faces the tongue. Its mucosa is covered by stratified squamous epithelium with glands, mostly mucous, which make this investing surface of the epiglottis slippery for swallowing. The stratified epithelium 'climbs over' from the front of the epiglottis on to the aryepiglottic folds and the posterior epiglottic surface, and often passes surprisingly low down into the vestibule before being replaced by the ciliated variety; there is no constant dividing line between the two. There may also be scattered squamous islands in the ciliated part of the vestibule, but *over the vocal folds the epithelium is always stratified squamous*; cilia here would be rubbed off by their mutual contact. The folds are a whitish colour since blood vessels do not show through here, due to the firm attachment to the vocal ligament. There are scattered mucous glands but the saccule contains a concentration of them, whose secretion flows down to lubricate the vocal folds.

The *lamina propria* is loose in all parts except over the vocal folds where it is very firmly attached. It therefore allows great swelling except at the glottis; in *oedema of the glottis* the swelling accumulates above the rima because it cannot disperse over the watershed of the vocal folds, but may still cause dangerous obstruction to the airflow.

INTRINSIC MUSCLES

The intrinsic muscles of the larynx are best considered in two groups: those that alter the size and shape of the inlet, and those that move the vocal folds. The muscles that form a sphincter for the inlet are the aryepiglottic and oblique arytenoid muscles, assisted by the transverse arytenoid, and if the aryepiglottic fibres are poorly developed, by the thyroepiglottic muscles. Those responsible for phonation by moving the vocal folds are

the posterior and lateral cricoarytenoids, thyroarytenoids and vocalis, transverse arytenoid and the cricothyroids.

Muscles of the inlet

The **aryepiglottic muscle** lies within the fold of that name (Figs 6.37A and 6.38), and runs from the side of the epiglottis to the muscular process and posterior surface of the arytenoid cartilage of the same side. Joining the uppermost part of the muscle are the fibres of the **oblique arytenoid** (Fig. 6.38), which pass from the muscular process of one arytenoid to the top of the aryepiglottic muscle of the opposite side, with some fibres becoming attached to the (opposite) corniculate cartilage. The two oblique arytenoids thus cross one another like an X superficial to the transverse arytenoid (see below). The **thyroepiglottic muscle** arises from the upper border of the lamina of the thyroid cartilage. Its fibres lie outside the quadrangular membrane, on which they run to be inserted into the side of the epiglottis.

The aryepiglottics and oblique arytenoids act as a sphincter for the inlet; they oppose the arytenoid cartilages to each other and draw the epiglottis down to bring its lower half into contact with the arytenoids. Sometimes the free edge of the aryepiglottic fold contains no aryepiglottic muscle fibres, in which case the oblique fibres are well developed and the thyroepiglottic muscles assist in approximating the epiglottic to the arytenoid cartilages.

The aperture of the inlet thus closed forms an effective valvular protection from above (i.e. against swallowed material) even without the epiglottic lid that normally is an added refinement. It can be readily opened by air pressure from below, such as an inescapable cough during swallowing.

Muscles of the vocal folds

These have easy names, determined by the cartilages to which they are attached. They work in opposing groups, and are best studied in their functional opposing pairs. The only movements they impart to the vocal folds are (1) opening and closing and (2) lengthening and shortening, with or without tensing and relaxing.

The opening and closing movements, usually called *abduction* and *adduction* of the vocal folds, occur at the cricoarytenoid joints. Abduction is produced by the posterior cricoarytenoid which has two distinct actions, each of which is opposed by a separate adductor muscle, the lateral cricoarytenoid and the transverse arytenoid.

The **posterior cricoarytenoid** is the most important single muscle in the larynx and perhaps in the whole body, since it is the only abductor of the vocal folds, i.e. the only dilator of the rima of the glottis. It arises from the concavity on the back of the lamina of the cricoid cartilage (Fig. 6.38), whence its fibres converge on the muscular process of the arytenoid cartilage. Its upper fibres are almost horizontal, its lateral fibres almost vertical (Figs 6.37B and 6.39). Their combined action is to cause lateral movement of the arytenoid, away from the midline, with slight rotation due to the shape of the cricothyroid joint surfaces (see above) tilting the vocal process laterally, thus producing abduction of the vocal fold.

The **lateral cricoarytenoid** arises from the upper border of the cricoid arch (Figs 6.37B and 6.39). Its fibres pass backwards and upwards beneath the thyroid lamina to attach themselves to the muscular process of the arytenoid. The action of the muscle, in drawing the muscular process forwards, is to cause the vocal processes to approximate each other, counteracting any rotation produced by the posterior cricoarytenoid.

The **transverse arytenoid** consists of a strong mass of transverse fibres which connect the posterior and part of the medial surfaces of the arytenoid cartilages to each other (Fig. 6.38). Contraction of this muscle draws the arytenoid cartilages upwards along the sloping shoulders of the cricoid lamina, approximating them without rotation.

The **cricothyroid**, the only laryngeal muscle visible in anterior dissections of the neck, is a triangular muscle which diverges from the arch of the cricoid

backwards to fan out towards its attachment to the inferior horn and lower border of the thyroid lamina (Fig. 6.40). Its contraction causes the arch of the cricoid and the Adam's apple to approach each other. Usually the thyroid cartilage is tilted downwards towards the relatively fixed cricoid arch. The action of this muscle on the vocal fold is identical whether the thyroid moves on a fixed cricoid or vice versa. It is more readily understood if the thyroid cartilage is assumed to be fixed. Then, tilting upwards of the cricoid arch will tilt the lamina backwards; thus the vocal folds are *lengthened* (Fig. 6.41) and slightly adducted. Note especially that lengthening does not presuppose an increase in tension. The vocal folds consist of a felted membrane of fibroelastic tissue whose strands run in all directions. Squares of this network are converted into diamonds by increased length of the vocal folds without a corresponding increase of tension.

The **thyroarytenoid** is the opponent of the cricothyroid. It lies above and lateral to the free edge of the cricovocal membrane and lateral to the sinus and saccule. It extends from the back of the Adam's apple of the thyroid cartilage to the vocal process and anterior

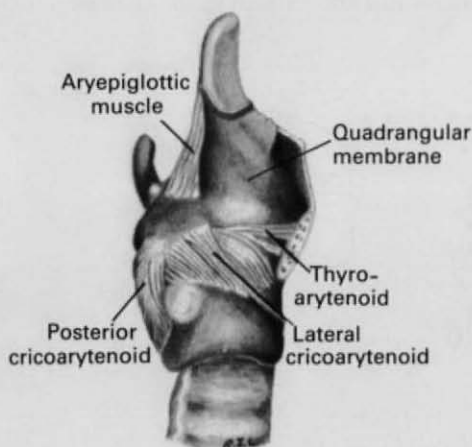


Fig. 6.39 Right quadrangular membrane and muscles of the larynx exposed by removal of the right half of the thyroid cartilage.

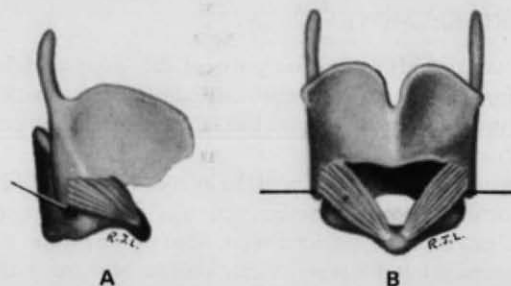


Fig. 6.40 Cricothyroid muscle, A from the right, B from the front. The pointer is directed to the axis of rotation at the cricothyroid joint.

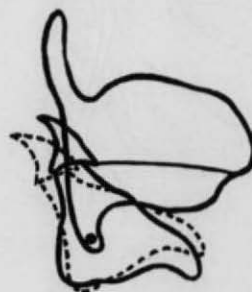


Fig. 6.41 Action of the cricothyroid. Approximation of the cricoid arch (from solid to interrupted outline) and thyroid lamina increases the distance between the arytenoids and Adam's apple, so that the vocal folds are elongated.

surface of the arytenoid cartilage (Figs 6.37B and 6.39). Its contraction *shortens* (not relaxes) the vocal folds. Certain lower fibres of this muscle extend from the arytenoid cartilage to the cricovocal membrane, falling short of the thyroid cartilage. They constitute the **vocalis muscle**. Their contraction pulls up portions of the cricovocal membrane, thereby increasing the vertical depth of the opposing surfaces of the vocal folds. This thickening of the opposing surfaces of the vocal folds is assisted by the contraction of the main bulk of the thyroarytenoid. The tension of the fold is not a function of its length, but of the tonic contraction of the thyroarytenoid. The length of the folds having been determined by the opposing contractions of the cricothyroid and thyroarytenoid muscles, their tension is now determined by the isometric contractile tonus of the thyroarytenoid, counterbalanced by the requisite opposing tonus of the cricothyroid. It is apparent that the longer the vocal fold the more readily can the stretched thyroarytenoid contract.

It must be emphasized that these changes in length and tension control the pitch of the voice and occur normally *only when the cords are in contact for phonation*.

INTRINSIC MOVEMENTS

The vocal folds and other parts of the larynx exhibit varying degrees of movement, depending on whether they are functioning for swallowing, respiration, phonation, or muscular effort.

Swallowing. Protection of the inlet during swallowing is provided by the sphincteric action of the aryepiglottic muscles. A second sphincter is provided by the rima of the glottis itself, but this is very rarely needed. Not only is the

larynx hauled up beneath the posteriorly bulging tongue, but the epiglottis itself is tilted backwards and downwards by the passing bolus, flipping down like a temporary lid over the laryngeal inlet (Fig. 6.42). Thus during swallowing the entry of a foreign body into the aperture of the larynx is a very rare event.

The inverted epiglottis is separated from the posterior wall of the pharynx by a large semisolid bolus (Fig. 6.42C) but it is in contact with the wall if the bolus is small, thus producing the lateral food channels (Fig. 6.43).

Respiration. The normal position of the vocal folds has been described above, and in quiet respiration there is minimal movement. When the maximal passage of air is required the folds are further abducted with some lateral rotation.

Phonation. Phonation or voice production involves the making of sounds that can be varied in pitch, intensity and quality (timbre). The stream of air emitted during phonation emerges as a series of discrete jets, as from a siren. This is not only a more effective means of sound production, but is very economical of expired air. At rest the vocal folds are separated, and have sharp edges. During phonation they are held together, and the cricovocal membrane is pulled up by the vocalis muscle, so that the folds are in contact over a vertical extent of the order of 3 mm below their free edges (Fig. 6.44). The apposed vocal folds are blown apart by the pressure of the air below them, and elastic recoil returns them to their original position; the rapid repetition of these movements results in vibration of the folds, so giving rise to sound waves with a certain *pitch*. The frequency of emission of the jets depends on the length, tension and shape (mass) of the folds, and it is these features that are adjusted by the intrinsic muscles

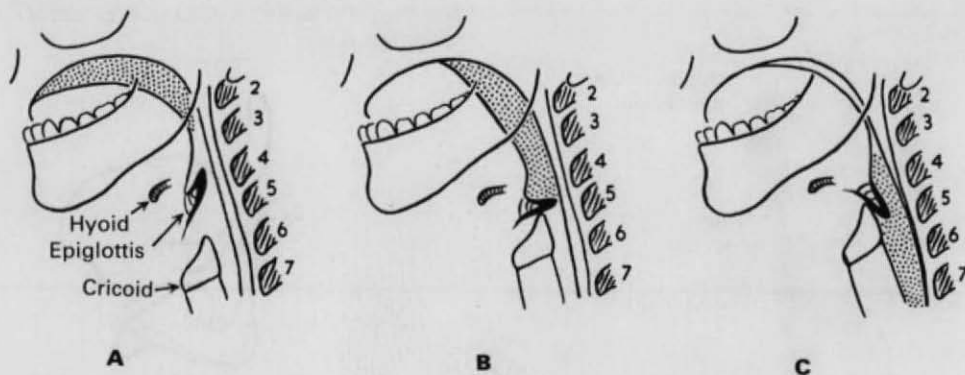


Fig. 6.42 Stages of swallowing (traced from a cineradiograph). **A** The bolus (stippled) enters the oropharynx. **B** The bolus is now within the oropharynx, the larynx has risen (see the cricoid outline) and the epiglottis is tilting, but the hyoid bone has not moved. **C** The bolus enters the oesophagus, the hyoid bone and larynx have together risen, and the epiglottis is inverted.

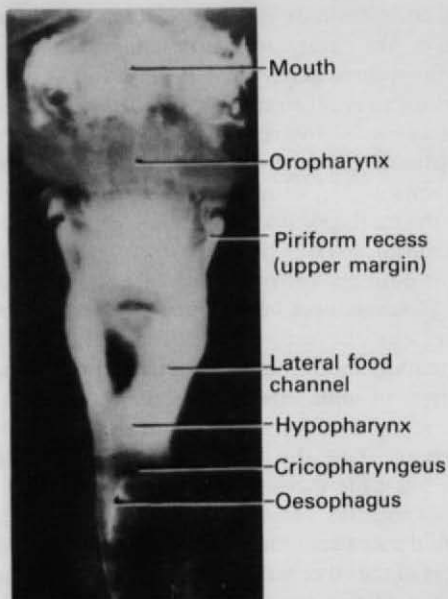


Fig. 6.43 Radiograph during swallowing, showing division of the bolus into the lateral channel (piriform recess) on each side of the larynx.

to vary the pitch. The *intensity* of the sound varies with the pressure of the air forced through the glottis. The *quality* or timbre of the voice depends on the resonating chambers above the glottis; these include the vestibule of the larynx, pharynx, mouth, nose and paranasal sinuses, and their overall shape and volume can be altered by the soft palate, tongue and other muscles. Depression of the larynx (p. 505) increases the volume of the resonating chambers. *Articulation* depends on breaking up the sound into recognizable consonants and vowels by the use of tongue, teeth and lips.

In *whispering* the vocal folds are separated, and vibrations are imparted to a constant stream of expired air. This is inefficient as a means of sound production, and is very wasteful of air.

Muscular effort. Various efforts such as heavy lifting, coughing and abdominal straining are accompanied by closure of the glottis, and also by some medial movement of the vestibular folds and compression of the laryngeal ventricle.

A **cough** or sneeze is an explosion of *compressed* air. The vocal folds are powerfully adducted, a strong expiratory contraction is made to build up the intrathoracic pressure (p. 251), the folds are then suddenly abducted and the blast of compressed air explodes through the larynx (its expulsive force increased by the simultaneous 'choke-barrel' narrowing of the trachea). In the **cough reflex**, afferents from the mucous membrane supplied by the glossopharyngeal and vagus nerves pass to the nucleus of the tractus solitarius (p. 610). There are widespread connexions in the brainstem and spinal cord for the efferent side of the reflex, which involves muscles of the larynx, pharynx, palate, tongue, diaphragm and other thoracic and abdominal muscles.

Abdominal straining is made more effective by adduction of the vocal folds. The diaphragm is weaker than the muscles of the anterior abdominal wall. To prevent loss of intra-abdominal pressure by upward displacement of the diaphragm the folds are closed after a deep breath and the diaphragm is forced up against a cushion of compressed air. This manoeuvre is used for evacuation of pelvic effluents and also for the straining of heavy lifting. Escape of a jet of compressed air causes the characteristic grunt.

The act of 'holding the breath' by powerfully adducted vocal folds may be to prevent either inspira-

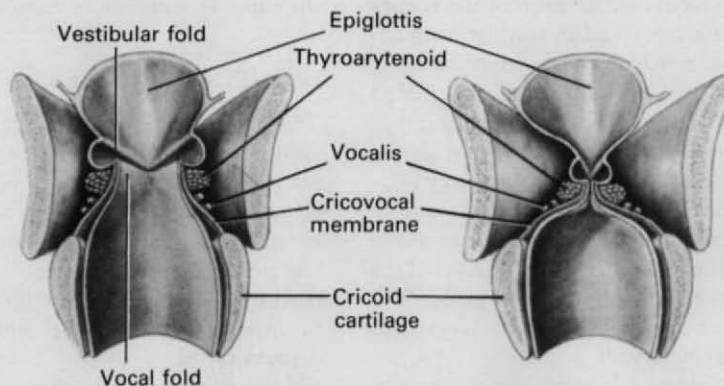


Fig. 6.44 Occlusion of the vocal folds during phonation, seen in coronal section looking towards the front.

tion or expiration. Air entry is prevented by the valve effect of the adducted vocal folds. This is used in powerful adducting movements of the upper limb, where the vocal folds in apposition prevent air entry, and so the adducting muscles do not waste their effort by elevating the ribs.

Blood supply

As in the innervation (see below), so in the vascular pattern, the vocal folds form a dividing line between the upper and lower halves of the larynx. *Above the vocal folds* blood is brought to the larynx by the superior laryngeal branch of the superior thyroid artery. This vessel enters the piriform recess with the internal laryngeal nerve by piercing the thyrohyoid membrane (Fig. 6.29). The superior laryngeal veins accompany the artery and empty into the superior thyroid veins.

The *lower half* of the larynx is supplied from the inferior laryngeal branch of the inferior thyroid artery; it accompanies the recurrent laryngeal nerve beneath the inferior constrictor of the pharynx. It supplies all of the larynx below the vocal folds. Venous return is by the inferior laryngeal veins to the inferior thyroid veins, which drain into the brachiocephalic veins, chiefly the left.

Lymph drainage

From the upper and lower halves of the larynx, lymphatics accompany the superior or inferior thyroid vessels and drain to the upper or lower groups of deep cervical nodes respectively. A few lymphatics run with veins to pretracheal nodes. These and the tracheo-bronchial group are also commonly involved in the spread of malignant disease.

Nerve supply

All the **muscles** of the larynx are supplied by the **recurrent laryngeal nerve** *except cricothyroid* which is innervated on its external surface by the *external laryngeal nerve*. All the motor fibres in both nerves are derived from the cranial part of the accessory nerve from cell bodies in the lower part of the nucleus ambiguus.

The recurrent laryngeal nerve enters the pharynx by passing upwards *under the lower border of the inferior constrictor behind the cricothyroid joint*. By this level it is often double, having divided into two at the level of the upper border of the isthmus of the thyroid gland. The nerve reaches the lower part of the piriform recess and then penetrates the laryngeal wall.

With *complete recurrent laryngeal nerve paralysis* the vocal fold takes up a half-abducted position (sometimes called the cadaveric position, but the

position after death is not identical). The arytenoid cartilage on the paralysed side lies slightly in front of that on the normal side. There is vibration of the fold and stridor (noisy respiration) if the airflow is substantially increased for any reason, and the voice becomes hoarse (though 50% show some later improvement due to compensatory movement of the other vocal fold towards the midline). With *partial* lesions of the recurrent laryngeal nerve, the vocal fold takes up an adducted position or may even cross the midline slightly. There is as yet no generally acceptable explanation for why the only abductor muscle (posterior cricoarytenoid) should be apparently more vulnerable to this type of injury than the adductors. From the point of view of airway obstruction, the partial lesion is more serious than the complete lesion; a bilateral partial lesion is life-threatening.

Paralysis of the *external laryngeal nerve* affecting cricothyroid may pass unnoticed, or perhaps cause some hoarseness of the voice which appears to recover (due to hypertrophy of the opposite cricothyroid) but with a residual inability to produce higher frequencies, as in the higher notes in singing. However, careful examination may reveal that the vocal fold on the damaged side is at a slightly lower level than the normal, due to loss of the tension normally provided by cricothyroid.

The **mucous membrane** of the larynx *above the level of the vocal folds* is supplied by the **internal laryngeal nerve**, and that *below the folds* by the **recurrent laryngeal nerve**. The cell bodies of the afferent fibres of both nerves are in the inferior vagal ganglion. Both nerves also carry secretomotor fibres for glands, with cell bodies in the dorsal vagal nucleus. Note that the recurrent laryngeal supplies muscles and mucosa, but the internal laryngeal is only sensory.

The sympathetic supply (vasoconstrictor) comes in with the superior and inferior laryngeal arteries from the superior and middle cervical sympathetic ganglia.

EXTRINSIC MUSCLES

The larynx moves upwards during the act of swallowing and afterwards returns to the position of rest. Two opposing groups of muscles exist, the one elevating and the other depressing the larynx. It is to be noted that an elevator of the hyoid bone must elevate the larynx by transmitting its pull through the thyrohyoid membrane to the thyroid cartilage, and that the larynx cannot be depressed without an equal depression of the hyoid. Normally after elevation of the larynx the return to the position of rest is by elastic recoil of the trachea, though there are depressor muscles too.

Elevators

Any muscle that elevates the hyoid bone will *indirectly* assist in elevating the larynx. These include mylohyoid, digastric, stylohyoid and geniohyoid, and their actions are discussed on page 428. The muscles that act directly on the larynx to raise it are thyrohyoid (p. 429), stylopharyngeus (p. 489), palatopharyngeus (p. 494), salpingopharyngeus (p. 489), and the *inferior* constrictor (p. 488). At first sight it is unexpected that the *inferior* constrictor should be an *elevator*, but it does so because its uppermost fibres pass very high up on to the pharyngeal raphe (Fig. 6.27).

The three muscles, stylopharyngeus, salpingopharyngeus and palatopharyngeus are all badly named. In each case their essential insertion is into the larynx, though certain of their fibres fade out inside the lateral wall of the pharynx. Their attachments to the larynx are chiefly into the posterior border of the lamina and horns of the thyroid cartilage, though some of their fibres encroach a little on the upper border of the thyroid lamina just in front of the superior horn. They should rightly be named the stylolaryngeus, salpingolaryngeus and palatolaryngeus and because of their attachments they are elevators of the larynx.

Depressors

The infrahyoid muscles sternohyoid and omohyoid (p. 429) will indirectly assist in depressing the larynx by pulling the hyoid bone down, but sternothyroid (p. 429) acts directly on the larynx. The tendon of the oesophagus is attached to the middle of the back of the cricoid cartilage (p. 434), and this also helps to return the elevated larynx to the normal position. Generally the position of rest is attained by the elastic recoil of the trachea. Active depression increases the capacity of the resonating chambers during phonation and thus affects the quality of the voice.

Development

The larynx develops from the tracheobronchial groove in the caudal end of the floor of the primitive pharynx, with the laryngeal cartilages being derived from the fourth and sixth arches. Cricothyroid is from the fourth arch; the precise origin of the other muscles is uncertain.

Laryngotomy

For an emergency laryngotomy (preferred to tracheotomy — p. 433) the laryngeal prominence and

cricoid cartilage are palpated and entry is made through the cricothyroid ligament between the cricoid and the lower border of the thyroid cartilage. There are no large midline vessels here as there may be in front of the trachea. This site is also used for the insertion of a minitracheal tube (for suction rather than as an airway).

PART 15 ORBIT AND EYE

The **eye** (eyeball) is the organ of vision and the principal component of the visual apparatus which also includes various accessory ocular structures, all lodged in the orbit, the bony space in the front of the skull. The *orbital fascia* is the periosteum of the orbit which, at the back, becomes continuous with the dura mater and the sheath of the optic nerve. The accessory structures include the extraocular muscles which move the eye, the eyelids, conjunctiva and the lacrimal gland (part of the lacrimal apparatus, which, although not all within the orbit, is conveniently considered here). Orbital fat fills the spaces in the orbit. In particular it surrounds the optic nerve and makes a cushion to stabilize the eye against the backward pull of extraocular muscles. It remains very constant in volume during any changes in disposition of the general body fat and fluid.

ORBIT

Examine a skull. The **orbit** is a bony cavity shaped like a pyramid tilted on to one side, with the apex at the back and the base forming the opening (aditus) on the front of the facial skeleton (Fig. 6.45). The roof of the orbit is the orbital part of the frontal bone, with the lesser wing of the sphenoid at the most posterior part. At the front on the medial side, the frontal sinus lies between the orbital and squamous parts of the frontal bone and extends for a variable distance above the roof (Fig. 8.6, p. 656).

The **medial wall**, 5 cm (2 in) long, extends in front from the anterior lacrimal crest on the frontal process of the maxilla, backwards across the lacrimal bone and the orbital plate of the ethmoid, to the body of the sphenoid and the optic canal. The posterior lacrimal crest is a vertical ridge on the lacrimal bone. Between the two crests is the *fossa for the lacrimal sac*; the fossa is the upper end of a groove that leads down into the *nasolacrimal canal*. At the junction of medial wall and roof lie the *anterior* and *posterior ethmoidal foramina*,

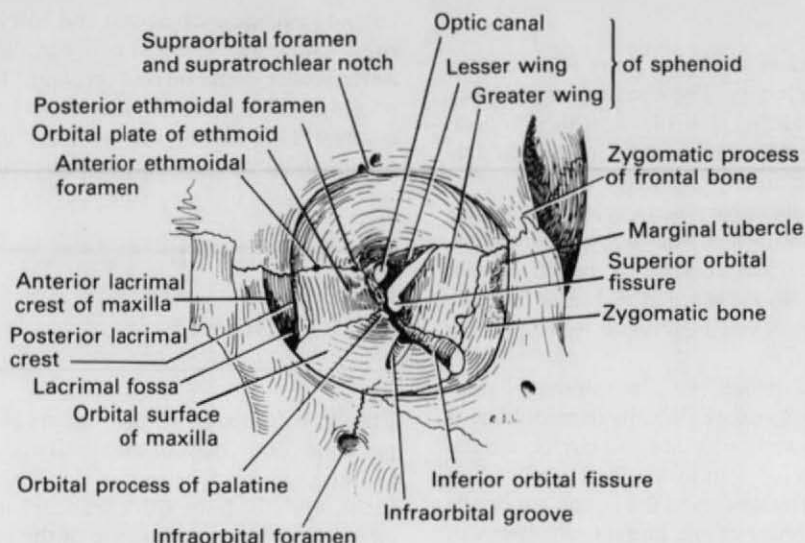


Fig. 6.45 Bones of the left orbit, viewed along the orbital axis which is at 25° to the sagittal plane.

between the ethmoid and frontal bones. The medial walls lie anteroposterior, parallel with each other. They separate the orbits from the ethmoidal air cells and the lateral walls of the nose.

The **lateral wall**, also 5 cm (2 in) long, is composed of the zygomatic bone, with the *marginal tubercle* (of Whitnall) just inside the upper part of the anterior margin, and the greater wing of the sphenoid. Posteriorly there is a gap, the *superior orbital fissure*, between lateral wall and roof (greater and lesser wings of the sphenoid), leading into the middle cranial fossa. A further gap, the *inferior orbital fissure*, diverges from the medial end of this fissure between lateral wall and floor (greater wing and maxilla); it leads into the pterygopalatine and infratemporal fossae. The lateral wall separates the orbit from the temporal fossa in front and from the middle cranial fossa behind. The lateral wall slopes at 45° to the sagittal plane; the two lateral walls are at right angles to each other, and, if prolonged backwards, would meet at a right angle in the pituitary fossa.

The **floor** consists of the orbital surface of the maxilla (grooved and canalized by the infraorbital nerve), completed in front by the zygomatic bone laterally and completed behind by a tiny piece of bone at the apex, the orbital process of the palatine bone.

The **orbital margin** consists of four curved sides. It slopes downwards from the nose. The supraorbital margin (frontal bone) is notched or canalized near its

medial end for the passage of the supraorbital nerve and artery, and slightly more medially is the frontal notch or foramen for the supratrochlear nerve and vessels. The lateral margin is formed by the conjoined processes of the frontal and zygomatic bones. The infraorbital margin is formed half and half by zygomatic bone and maxilla, which meet at a suture. An irregular suture leads from this margin into the infraorbital foramen, indicating the sinking of the infraorbital nerve through the bone from its original passage around the infraorbital margin. The suture closes in later life and is not seen in elderly skulls. The *medial margin* of the orbit is the anterior lacrimal crest.

EYELIDS

The **eyelids** are covered in front with loose skin and behind with adherent conjunctiva. Their skeletal framework is the orbital septum, thickened at the margins of the lids to form the tarsal plates. The orbicularis oculi muscle lies in front of the septum.

The **orbital septum** is attached to the anterior lacrimal crest and to the margins of the orbit (Fig. 6.46). It has a wide 'buttonhole' in it: the palpebral fissure between the lids. It is not of equal density throughout. It is greatly thickened at the upper margin of the buttonhole to form the crescent-shaped **superior tarsal plate** and similarly, though to a smaller extent, in the lower margin to form the **inferior tarsal plate**. The plates

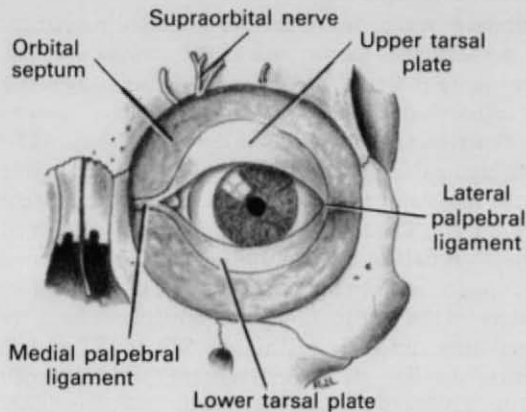


Fig. 6.46 Left orbital septum.

are formed of dense fibrous tissue, not cartilage as might be imagined from their stiffness. From the medial end of the buttonhole to the anterior lacrimal crest the orbital septum is thickened; this is the **medial palpebral ligament**, which anchors the tarsal plates to the anterior lacrimal crest. The corresponding **lateral palpebral ligament** is a much thinner structure which fuses with the lateral palpebral raphe of orbicularis oculi (p. 446) to become attached to the marginal tubercle of the zygomatic bone (Fig. 6.45).

In front of the tarsal plates and orbital septum lie the curving fibres of the palpebral part of orbicularis oculi (p. 446). The angular vein and termination of the facial artery lie superficial to the orbicularis at the **medial canthus** (the commissure where upper and lower lids meet). In front of the muscle fibres is thin skin overlying a loose fibrous subcutaneous tissue. The skin is thin and densely adherent to the margins of the palpebral fissure; here, just outside the margin, are the **eyelashes**, long hairs whose follicles are stabilized by being attached to the rigid tarsal plates.

The **tarsal plates** are crescent-shaped laminae of very dense fibrous tissue, curved to the curve of the eyeball. They are rigid and retain their curve after being distorted. As well as anchoring the roots of the eyelashes they contain the **tarsal (Meibomian) glands**. These modified sebaceous glands secrete an oil that makes the lid margins waterproof and, covering the tears on the cornea, delays their evaporation. The palpebral conjunctiva is firmly adherent to the deep surface of each tarsal plate, so it is not wrinkled by eyelid movements.

At the medial end of each lid margin is a low elevation, the **lacrimal papilla**, surmounted by a minute **lacrimal punctum**. This opens into a **lacrimal canaliculus**, a tiny canal which conveys excessive tears to the lacrimal sac.

Blood supply. Both lids are supplied by palpebral branches of the ophthalmic artery.

Nerve supply. The skin of the upper lid is supplied by the lacrimal, supraorbital, supratrochlear and infratrochlear nerves, and that of the lower lid by the infraorbital nerve. The same nerves supply the conjunctiva that lines each lid — see below.

Movements. The lower lid possesses very little mobility, the upper lid a great deal. The lids are closed gently by the palpebral fibres and forcibly when the orbital fibres of the orbicularis oculi join in (p. 447). The lids are opened in the ordinary way by levator palpebrae superioris (p. 509). The levators hold the lids open while the orbital fibres of orbicularis are contracting to lower the eyebrows as a pair of sun visors. The sun visors can be brought together by corrugator supercilii, causing (unwanted) vertical wrinkles between them.

Conjunctiva

This transparent membrane is attached to the sclera at the margins of the cornea, with which it blends. It is loosely attached over the anterior part of the sclera and thence reflected to the inner surfaces of the eyelids. It is firmly attached to the tarsal plates and blends with the skin at the margins of the lids. A fold near the medial canthus, the *plica semilunaris*, is sometimes considered to be homologous with the nictitating membrane (third eyelid) of some animals. Its slack allows lateral deviation of the cornea. Elsewhere the slack conjunctiva is tucked in as the fornices; the presence of the lacrimal canaliculi and sac prevents any infolding here at the medial canthus. At the medial canthus is a small pimple of modified skin, the *caruncle*. Between plica and caruncle is the **lacus lacrimalis**, a conjunctival recess bounded by hairless lid margins; in the lacus excessive tears accumulate before passing into the canaliculi.

The conjunctiva consists of fibrous tissue covered with wear-and-tear epithelium (stratified squamous) except for scattered islands mainly in the upper fornix. These are islands of columnar epithelium, all the cells of which are goblet cells, secreting mucus. Into the superior fornix of the conjunctiva the lacrimal gland opens laterally by 15 or more separate little ducts. A flange from the tendon of levator palpebrae superioris is attached along the superior fornix.

Nerve supply. The palpebral and adjoining scleral surfaces of the conjunctiva are supplied by the nerves of the overlying eyelid skin — see above. Note that the cornea has a separate supply from the long and short ciliary nerves (p. 517).

LACRIMAL APPARATUS

The production of tears and the removal of excess tears is the function of the lacrimal apparatus, which consists of the lacrimal gland, lacrimal canaliculi, lacrimal sac and the nasolacrimal duct.

Lacrimal gland

This is a *serous* gland with a large orbital and a small palpebral part. The orbital part lies in the lacrimal fossa on the lateral part of the roof of the orbit, supported by the lateral edge of the aponeurotic tendon of levator palpebrae superioris. It curls round the lateral margin of the tendon and turns forward as the palpebral part, visible through the superior fornix of the conjunctiva. The levator tendon and orbital fat keep the gland in place. The dozen or more *ducts* lead from the palpebral part into the lateral extent of the superior fornix; those from the orbital part pass through the palpebral part. Secretomotor fibres from the superior salivary nucleus travel in the greater petrosal nerve and relay in the pterygopalatine ganglion. The postganglionic fibres run with the zygomatic nerve and reach the gland via its anastomotic branch with the lacrimal nerve.

Under normal conditions the lacrimal gland secretes just enough tears to replace those lost by evaporation. Closing of the eyes (p. 447) begins at the lateral side of the upper lid and moves medially, so spreading tears across the eye.

The gland develops from the upper outer part of the conjunctival sac as a series of epithelial buds which differentiate into alveoli and ducts.

The *lacrimal sac* (see below) is an emergency apparatus for removing excessive tears to clear the vision. Excessive tears are discouraged from spilling over on to the cheeks by the waterproof lid margins, greased by the secretion of the Meibomian glands. The eye can be 'brimful of tears' before it spills. Opening and closing the lids (blinking) pumps the tears out of the conjunctival sac, and the movement is accelerated during times of increased tear production. Blinking, however, serves a much more important function: that of moistening the corneal epithelium. The upper lid acts like a windscreen wiper; it leaves a film of tears on the cornea. The *tear film* consists of an outer oily layer (from sebaceous glands of the lids and caruncle), a middle aqueous layer (lacrimal secretion), and a posterior layer of mucus (from conjunctival goblet cells). The oily layer helps to retard evaporation. The **blinking reflex** is set off by dryness of the cornea to replace the precorneal film, or by excessive tears to pump them into the nose. It is produced by the palpebral fibres (not

the orbital fibres) of orbicularis oculi, and the movement does not diminish the volume of the conjunctival sac. 'Screwing up the eyes' by the orbital fibres compresses the conjunctival sac, and an eye brimful of tears is caused thereby to spill over down the cheek (see p. 447).

The lacrimal canaliculi lead from the puncta to the lacrimal sac; flap valves of mucous membrane prevent reflux of tears. The **lacrimal sac** lies in its fossa formed by the lacrimal grooves of the maxilla and lacrimal bone, crossed in front by the medial palpebral ligament and some of the palpebral fibres of orbicularis oculi are inserted into the walls of the sac. When the muscle contracts the lids are closed and the puncta turned inwards to dip into the lacus lacrimalis. Simultaneously the sac is drawn widely open, so that tears are sucked up through the canaliculi. When the muscle relaxes the lacrimal sac contracts by its own elasticity and pumps its contents down the nasolacrimal duct. There is much elastic tissue in the wall of the lacrimal sac, which is really the blind upper end of the nasolacrimal duct.

The **nasolacrimal duct**, 2 cm long, slopes downwards and *laterally*, in conformity with the pear-shaped nasal cavity, to open in the inferior meatus rather more than 2 cm behind the nostril. It is a tube with an internal diameter of 3.5 mm and a surprisingly thick wall. The mucous membrane is raised into several variable folds which act as valves to prevent air being blown up the duct into the lacrimal sac. The valves enforce one-way traffic in both canaliculi and nasolacrimal duct. Blinking pumps the lacrimal sac like a rubber syringe, sucking excess fluid from the conjunctival sac and squirting it down into the nose.

MUSCLES OF THE ORBIT

The eye is supported in the anterior part of the orbit and is moved by the extrinsic or **extraocular muscles** — four rectus muscles (superior and inferior, medial and lateral) and two oblique (superior and inferior). This makes six extraocular muscles, but there are two others within the orbit; levator palpebrae superioris for moving the upper lid, and a fragment of smooth muscle, the orbitalis (on the orbital floor) which is of little human interest but significant in comparative anatomy.

The eye does not lie symmetrically in the axis of the orbit. The two eyes face forwards parallel with each other. The medial walls of the orbits are parallel, but the lateral walls slope away to make a right angle with each other. The optic nerve and ocular muscles come from the apex of the orbit, at the back of the medial wall, and pass laterally, not straight forwards, to their ocular attachments.

Examine a skull. The superior orbital fissure is retort-shaped, with the broad end medially (Fig. 6.45). A *tendinous ring* surrounds the 'bulb of the retort' and the optic foramen (Fig. 6.47B). It is attached to bone except where it bridges the 'neck of the retort'. From the ring the four recti arise; from the bone above the ring the levator palpebrae superioris and the superior oblique take origin. As these muscles pass forwards from the apex of the orbit they broaden out, to form a *cone of muscles* around the eye. Many nerves pass through the superior orbital fissure (Fig. 6.20). Three pass through the lateral part, outside the fibrous ring, and they remain *outside the cone of muscles*. They are the lacrimal, frontal and trochlear nerves. The rest of the lateral part of the fissure is closed by the fibrous layer of the dura mater of the middle cranial fossa. The nerves that pass through the tendinous ring enter the cone of muscle; those destined for the eyeball or ocular muscles remain *inside the cone*. The only branches that pass out penetrate *through the cone beneath the superior oblique muscle*; they are the posterior and anterior ethmoidal and the infratrochlear nerves, all branches of the nasociliary nerve. If these points are grasped, the disposition of the nerves in the orbit becomes intelligible.

The effect that muscle actions have on the eye can be described in various ways; for example, moving the eye so that the cornea and pupil move inwards towards the nose can be called adduction, medial rotation or nasal deviation. But simple English is best, and here we shall use 'turn in' for this example, and the corresponding turn out, turn up and turn down for the other major directions of movement.

The unimportant *orbitalis* muscle consists of some visceral muscle fibres that bridge the inferior orbital fissure. In animals that have no bony lateral wall to the orbit the muscle is large.

Levator palpebrae superioris arises from the under surface of the lesser wing of the sphenoid at the apex of the roof of the orbit. It is a flat muscle that broadens as it passes forwards (Fig. 6.47A). The thick frontal nerve lies on its upper surface, dividing towards the front of the orbit into its supraorbital and supratrochlear branches. At the anterior end the muscle forms a ribbon-like tendon that is projected on each side into a pair of crescentic horns. This broad tendon is inserted into the superior tarsal plate. In front a flange penetrates the orbital septum and palpebral muscle to become attached to the skin of the upper lid, while behind a weaker flange is attached to the superior fornix of the conjunctiva. A thin sheet of smooth muscle lies beneath the main tendon; it passes into the upper margin of the tarsal plate.

Nerve supply. By the superior division of the oculo-

motor nerve. The branch either pierces the superior rectus or passes on its medial side to enter the lower surface of the levator. The nerve also carries the sympathetic fibres for the visceral muscle part; the fibres have their cell bodies in the superior cervical ganglion. Stimulation of the cervical sympathetic results in widening of the palpebral fissure (this is not true exophthalmos).

Action. The muscle opens the eye by elevating the upper lid. Complete oculomotor palsy causes *complete* ptosis (drooping of the upper lid); division of the cervical sympathetic causes *slight* ptosis. An intact sympathetic part is not sufficient to compensate for loss of function of the skeletal part. Note that facial nerve paralysis does not cause ptosis but prevents 'screwing up' the lids (p. 641).

The **superior rectus** arises from the upper part of the tendinous ring and from the dural sheath of the optic nerve. It passes forward and laterally beneath the levator (Fig. 6.47A) and pierces the fascial sheath of the eye (p. 511); its tendon is inserted into the upper part of the sclera anterior to the coronal equator of the eye.

The **medial rectus** arises from the medial part of the tendinous ring and from the dural sheath of the optic nerve. It passes along the medial wall of the orbit below the superior oblique muscle and, piercing the fascial sheath, its tendon is inserted into the medial surface of the sclera anterior to the coronal equator of the eye.

The **inferior rectus** arises from the lower part of the tendinous ring. It deviates laterally as it passes forwards to the eye. Its tendon pierces the fascial sheath and is inserted, anterior to the coronal equator of the eye, into the inferior surface of the sclera. An expansion from the fascial sheath passes above the inferior oblique into the inferior tarsal plate.

The **lateral rectus** arises from the lateral convexity of the tendinous ring, in continuity across the superior orbital fissure from the bone above to the bone below. Its origin is thus C-shaped and longer than that of the other recti; upper and lower limbs of the C are usually referred to as the upper and lower heads of origin, but actually there is only one continuous curved origin. The muscle passes along the lateral wall of the orbit (Fig. 6.47A) and, piercing the fascial sheath, its tendon is inserted into the lateral surface of the sclera in front of the coronal equator of the eye.

The **superior oblique** arises from the body of the sphenoid by a narrow tendon above and medial to the tendinous ring and its rounded belly passes forward above the medial rectus (Fig. 6.47A). It gives way to a slender tendon (Fig. 6.93), which passes through the trochlea (where it is lubricated by a synovial sheath)

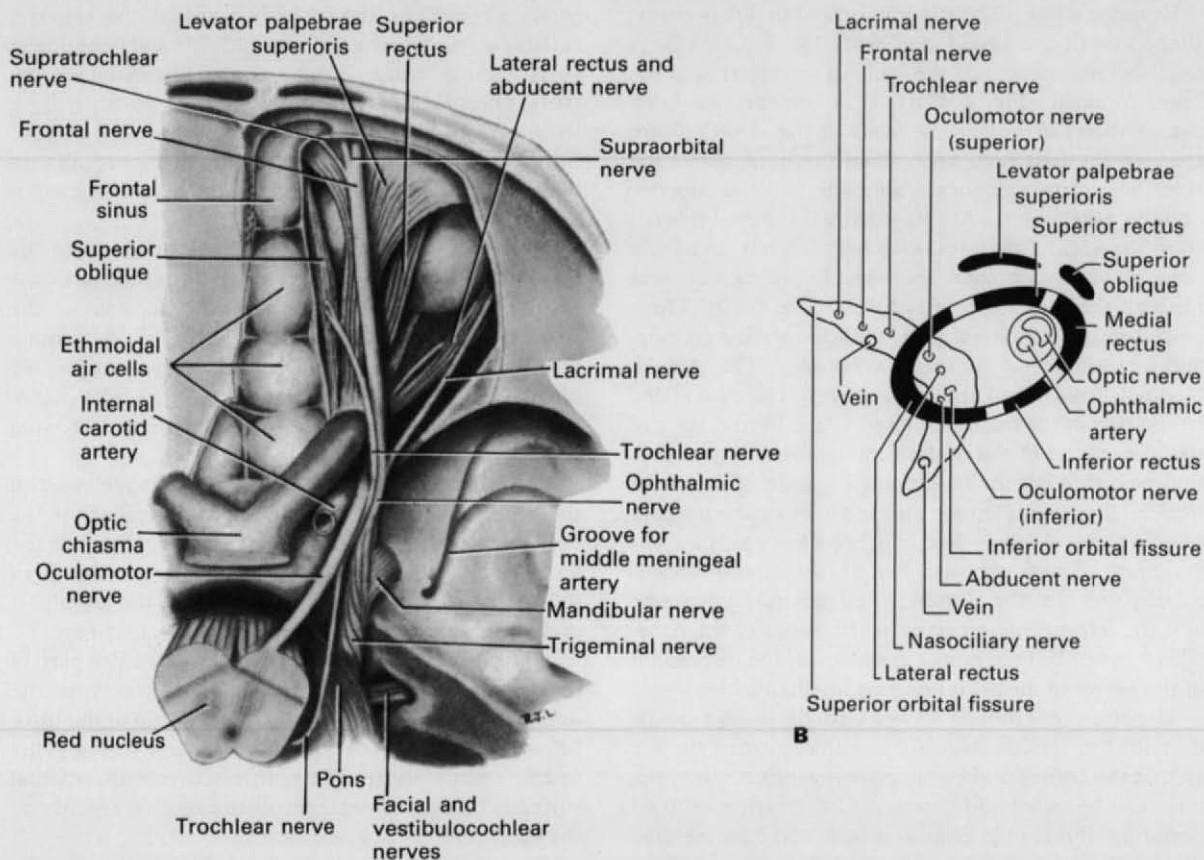
**A**

Fig. 6.47 Right orbit. **A** Dissection from above after removal of the roof (part of the anterior cranial fossa). **B** Diagram of the tendinous ring and structures passing through the ring and the orbital fissures.

and turns backwards and laterally to pierce the fascial sheath and pass *under the superior rectus*. It is inserted into the posterosuperior quadrant of the sclera (i.e. *behind the coronal equator of the eye*). The **trochlea** (pulley) is a loop of dense fibrous tissue attached to a small depression (trochlear fovea) or elevation (trochlear spine) on the under surface of the frontal bone (beneath the frontal sinus) a few millimetres behind the superomedial angle of the orbital margin (Fig. 8.6, p. 656).

The **inferior oblique** arises from the floor of the orbit vertically beneath the trochlea—the only ocular muscle not to arise from the back of the orbit. A small depression or rough area of bone on the orbital surface of the maxilla adjacent to the nasolacrimal canal is occasionally seen, but usually the muscle leaves no mark. The muscle passes obliquely back (Fig. 6.48) *below the inferior rectus* and curls up to insinuate itself

between the lateral rectus and the sclera. It is attached into the posteroinferior quadrant of the sclera (i.e. behind the coronal equator of the eye).

Nerve supplies. A mock 'chemical formula' is an aid to memorizing the nerve supplies of the eye muscles: $LR_6SO_4O_3$. This signifies that the **Lateral Rectus** is supplied by the *sixth* (abducent) nerve, the **Superior Oblique** by the *fourth* (trochlear) nerve, and the **Others** (superior, medial and inferior rectus and inferior oblique) by the *third* (oculomotor) nerve. The nerves all enter the ocular surfaces of the respective muscles, and their courses are described below. Note that because of the decussation of fibres in the midbrain (p. 607), the trochlear nerve nucleus of one side supplies the superior oblique of the eye of the opposite side.

Actions. Considered below with movements of the eyes.

STABILITY OF THE EYE

The **fascial sheath of the eye** (fascia bulbi or Tenon's capsule) is applied like a bursa to the back of the eyeball from the corneoscleral junction to the attachment of the optic nerve. Its inner layer is thin and blended with the sclera. Its outer layer is pierced by the tendons of the four recti and two obliques, and is prolonged as a tubular investiture proximally along each tendon towards the muscle belly. This outer layer is not of equal density throughout. Over the lateral rectus the tubular prolongation is thickened to form the **lateral check ligament**, which is attached to the marginal tubercle (of Whitnall), a palpable (if not visible) elevation on the orbital surface of the zygomatic bone just within the orbital margin (Fig. 8.13, p. 662). Over the medial rectus the tubular prolongation is thickened as the **medial check ligament** which is attached to the posterior lacrimal crest on the lacrimal bone, at the same horizontal level as the marginal tubercle (Fig. 6.48). Between them the inferior part of the sheath is thickened as the **suspensory ligament** (of Lockwood), which forms a sling, like a hammock, for the support of the eye.

The eye does not rest on the floor of the orbit. It is suspended above this level by the suspensory ligament and, in fact, lies nearer the superior than the inferior orbital margin, as can be confirmed by simple palpation. The whole maxilla can be removed, with the side walls of the orbit up to the level of the marginal tubercle, without descent of the eye. Above this level removal of bone destroys the attachments of the suspensory ligament, the eyeball falls down, and intolerable diplopia results.

The two pupils always converge towards the object being viewed. The eye is very mobile in its socket (fascial sheath) rotating up or down or sideways, but with all these movements the eye does not pop in or out. In other words, it always rotates about a fixed

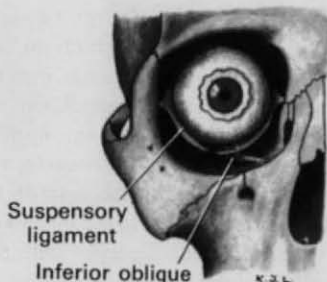


Fig. 6.48 Suspensory ligament of the right eye and the inferior oblique muscle which pierces the ligament.

centre, which is the geometrical centre of its own spheroid. Neither the resting nor the contracting recti displace the eye posteriorly.

The eye is prevented from posterior displacement by three factors: (1) the bony attachments of the recti; (2) the orbital fat; (3) the forward pull of the obliques.

The medial and lateral recti are attached to the bony margins of the orbit by the check ligaments and this attachment discourages *posterior* displacement of the eye.

The *orbital fat* lies within and without the cone of muscles and forms a cushion towards which the four recti can pull the eye back. If its volume increases (e.g. in hyperthyroidism) exophthalmos results, while if the volume decreases (e.g. in *extreme* dehydration) enophthalmos occurs. The volume of the orbital fat remains remarkably constant, unaltered by changes in general body fat.

The two obliques exert a *forward* pull of the eye. It is oblique in direction and may be thought to be a rather irrelevant factor. Nevertheless, it is known that the forward pull of the obliques can be considerable, as in the case of the stage comedian who by voluntary contraction of his obliques could so protrude the eyeballs that he could close his eyelids behind them, an astonishing performance that was brought to an untimely end by cellulitis of the orbit and meningitis following conjunctival ulceration.

NERVES OF THE ORBIT

The optic nerve, the nerve of vision (second cranial) from the optic chiasma, enters the orbit through the optic canal at the apex, inside the cone of muscles (p. 509). The nerves of the extraocular muscles (abducent, trochlear and the two divisions of the oculomotor), briefly referred to above and described further below, and the three branches of the ophthalmic nerve (lacrimal, frontal and nasociliary) enter through the superior orbital fissure, making seven nerves going through this fissure. The main nerves have all come through the cavernous sinus (p. 564). The infraorbital and zygomatic branches of the maxillary nerve pass from the pterygopalatine fossa to the orbit through the inferior orbital fissure. The frontal and infraorbital nerves are destined for the skin, and apart from some periosteal twigs they give no branches to the orbital contents; they use the orbit only as a means of transit.

The **infraorbital nerve**, accompanied by the infraorbital artery, occupies the groove in the posterior part of the orbital floor. Both enter the infraorbital canal and proceed to the face, also supplying the maxillary sinus and some upper teeth (p. 467).

The **zygomatic nerve** passes along the lower side of the lateral wall and enters the zygomatico-orbital foramen (Fig. 8.13, p. 662), where it divides into its *zygomaticotemporal* and *zygomaticofacial* branches (p. 451). Before the foramen it gives off its *communicating branch* to the lacrimal nerve, so providing the secretomotor fibres for the lacrimal gland (p. 508).

Optic nerve

The **optic nerve** enters the orbit through the optic canal, accompanied by the ophthalmic artery below and lateral to the nerve. The nerve is really an extension of the white matter of the brain; it is covered by pia mater and lies within a tube of arachnoid and dura mater as far as the back of the eye. Its length in the orbit is 3 cm, and it meets the sclera 3 mm medial to the posterior pole. From optic canal to sclera the nerve curves laterally and downwards as it passes forwards, and receives the vitally important central artery of the retina (p. 514). Near the back of the orbit after passing within the fibrous ring, the optic nerve is crossed obliquely and superficially from lateral to medial by the ophthalmic artery (see below), with the nasociliary nerve and the superior ophthalmic vein doing the same just behind the artery. The *ciliary ganglion* (see below) lies to the lateral side of the optic nerve one-third of the way from optic canal to eye, and the anterior part of the nerve is closely surrounded by the short ciliary nerves and vessels.

The continuation of the subarachnoid space around the optic nerve accounts for the appearance of *papilloedema* in increased intracranial pressure.

Blood supply. The intracranial part of the optic nerve is supplied by the anterior cerebral artery. In the orbit the posterior 2 cm receives a branch at the optic foramen from the ophthalmic artery. The anterior 1 cm is supplied by the central artery. As elsewhere in the central nervous system, these perforating vessels are end arteries.

Nerves outside the cone of muscles

Three nerves—lacrimal, frontal and trochlear—pass outside the tendinous ring and therefore remain outside the cone of the ocular muscles (see p. 509 and Fig. 6.47B).

The **lacrimal nerve**, the smallest of the three main branches of the ophthalmic, is a slender filament which runs forward on the lateral wall of the orbit along the upper border of the lateral rectus muscle (Fig. 6.47A). It picks up a branch from the zygomatic nerve (secretomotor, p. 34) which it gives off to the lacrimal gland. It

supplies periosteum and, piercing the orbital septum, reaches the skin of the outer part of the upper lid. It is accompanied in the distal part of its course by the lacrimal branch of the ophthalmic artery. It supplies both surfaces of the conjunctiva in the upper fornix.

The **frontal nerve** is a large main branch of the ophthalmic nerve which runs straight forward above the levator muscle in contact with the periosteum of the orbital roof (Fig. 6.47A). It supplies minute twigs to the periosteum and a branch to the mucous membrane of the *frontal sinus*. At a variable point overlying the levator it divides into the small supratrochlear and (laterally) the large supraorbital nerves (p. 451) which pass to the forehead and redivide. They are accompanied by corresponding branches of the ophthalmic artery.

The **trochlear nerve** (fourth cranial) has a simple course. Lying medial to the frontal nerve it passes forward across the origin of levator palpebrae superioris and sinks into the upper surface of the superior oblique muscle (Fig. 6.47A).

Nerves inside the cone of muscles

The oculomotor nerve enters the tendinous ring in two divisions, superior and inferior, with the nasociliary nerve between them and the abducent nerve below all three (Fig. 6.47B). The optic nerve (described above) lies medial and superior to this group, with the ophthalmic artery intervening.

The **abducent nerve** (sixth cranial) simply passes forward, diverging away from the optic nerve, and sinks into the ocular surface of the lateral rectus muscle, just below its middle (Fig. 6.47A).

The **superior division** of the oculomotor nerve (third cranial) runs forwards above the optic nerve and supplies the overlying superior rectus and levator palpebrae muscles one-third of the way along the orbit (Fig. 6.20). It carries sympathetic fibres from the cavernous plexus to the visceral-muscle part of the levator.

The **inferior division** of the oculomotor nerve is the larger of the two (Fig. 6.49). It immediately gives off the *nerve to the inferior rectus*, which runs along the upper surface of the muscle and sinks into it a third of the way along the orbit. Next arises the *nerve to the medial rectus*, which passes below the optic nerve and sinks into the ocular surface of the muscle, again a third of the way along the orbit. The rest of the inferior division continues as the *nerve to the inferior oblique*; it is the longest of the muscular nerves within the orbit, since it has to run along the lateral side of the inferior rectus above the orbital floor to reach the only muscle that does not arise from the apex of the orbit. This

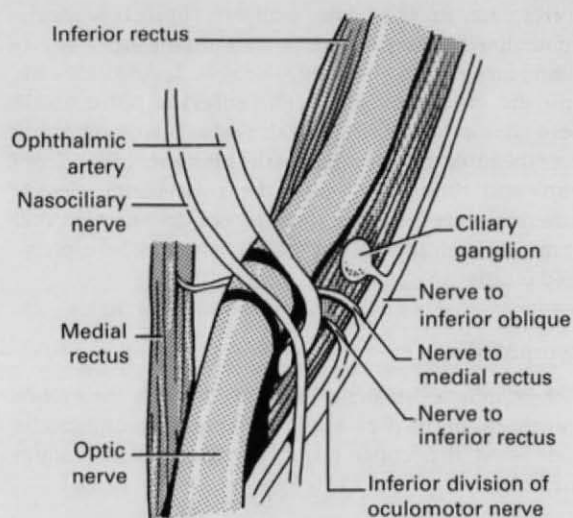


Fig. 6.49 Diagram of the right optic nerve and ciliary ganglion from above. The nasociliary nerve and ophthalmic artery curl over the optic nerve from the lateral side. The inferior division of the oculomotor nerve gives off the nerves to the inferior and medial recti, and then continues as the nerve to the inferior oblique which gives the branch to the ciliary ganglion conveying the preganglionic fibres (other ganglion connexions not shown).

inferior oblique nerve gives off the parasympathetic root to the ciliary ganglion (see below).

The **nasociliary nerve**, the third branch of the ophthalmic, is destined to change its name twice: first to the anterior ethmoidal on leaving the orbit to enter the nose, and then the anterior ethmoidal becomes the external nasal on leaving the nose as a cutaneous branch. After entering the tendinous ring it runs straight forward alongside (lateral to) the ophthalmic artery, then crosses from lateral to medial above the optic nerve and behind the ophthalmic artery (Fig. 6.49) to approach the medial wall of the orbit between the superior oblique and superior rectus. Here it becomes the **anterior ethmoidal** by entering the anterior ethmoidal foramen accompanied by the corresponding arterial branch, where it lies under the roof of the ethmoidal labyrinth, crosses the cribriform plate of the ethmoid and enters the nose by the nasal slit at the side of the crista galli. Proximal to entering the foramen the nasociliary gives off the **infratrochlear nerve** which, accompanied by a branch of the ophthalmic artery, passes forward on the medial wall of the orbit just below the trochlea (Fig. 6.93). It supplies nearby periorbitum, the lacrimal sac, conjunctiva and, passing *above the medial palpebral ligament*, is distributed to skin of the upper lid and the bridge of the nose.

Within the cone of muscles the nasociliary nerve gives off several branches. The most distal of these is the **posterior ethmoidal nerve**, which, accompanied by a branch of the ophthalmic artery, leaves the cone of muscles by the same route (beneath the superior oblique) and enters the posterior ethmoidal foramen for the supply of the posterior ethmoidal and sphenoidal air sinuses. The proximal branches of the nasociliary nerve remain within the cone.

The **sensory root of the ciliary ganglion** leaves the nerve at the fibrous ring and passes through the ciliary ganglion. The **long ciliary nerves**, two in number, pierce the posterior part of the sclera medial to the short ciliary nerves. The long ciliaries carry sympathetic fibres, which the nasociliary nerve has picked up from the cavernous plexus. Their cell bodies are in the superior cervical ganglion; they are motor to the dilator pupillae. A few sensory fibres supply the cornea; their cell bodies are in the trigeminal ganglion.

Ciliary ganglion

The **ciliary ganglion** is a minute body (2 mm diameter) lying on the lateral side of the optic nerve (Fig. 6.49) just in front of the ophthalmic artery as that vessel spirals around the nerve, and is about 8 mm from the apex of the orbit, i.e. a third of the way from the apex to the back of the eye (Fig. 6.93). Three roots enter its posterior end (Fig. 1.25, p. 34). The **sensory root** is a branch of the nasociliary nerve and passes through the ganglion without relay to supply the whole eye, cornea and sclera, iris and ciliary body, but not the conjunctiva. Division of this root abolishes the corneal reflex but not the conjunctival reflex. The **sympathetic root** is a branch from the cavernous plexus. It passes through the fibrous ring just below the nasociliary nerve, and passes through the ganglion without relay. It carries vasoconstrictor fibres to the vessels of the eye; its cell bodies are in the superior cervical ganglion. The **parasympathetic root** leaves the nerve to the inferior oblique and its fibres relay in the ganglion; their cell bodies are in the Edinger-Westphal nucleus.

The branches of the ciliary ganglion are the **short ciliary nerves**, a dozen or more in number. Each nerve contains fibres from all three roots of the ganglion. The nerves pierce the back of the sclera around the attachment of the optic nerve and then run in the supra-choroidal space. The vast majority of the postganglionic fibres from the cells of the ganglion supply the muscle of the ciliary body for accommodation (p. 519), allowing the lens to thicken and focus for near vision. Only 3% of the fibres supply the sphincter pupillae which consists of about 50 motor units. Sensory and sym-

thetic fibres supply the cornea, iris and ciliary body. Note that both groups of ciliary nerves, long and short, carry sensory fibres for the cornea, but only the short ciliaries are concerned with constricting the pupil and altering the shape of the lens.

VESSELS OF THE ORBIT

Ophthalmic artery

The **ophthalmic artery** is a branch of the internal carotid given off as that vessel emerges from the roof of the cavernous sinus. It passes through the optic canal, in which the optic nerve joins it from above. Both lie in a tubular prolongation of dura. Here the artery gives a branch to the posterior two-thirds of the orbital part of the optic nerve. In the orbit it pierces the dura and spirals around the lateral side of the optic nerve to pass forwards above the nerve, medial to the nasociliary nerve. Its many branches accompany all the branches of the nasociliary, the frontal and the lacrimal nerves, and it is hardly necessary to recite them all by name. Thus it supplies the ethmoidal air cells, part of the lateral wall of the nose, external nose, eyelids and forehead, in all of which places its branches anastomose with branches of the external carotid (maxillary, facial, superficial temporal) thus establishing connexions between internal and external carotid systems (p. 452). It should be noted that the two *terminal* branches of the ophthalmic artery are the *supratrochlear* and *dorsal nasal* (not the supraorbital, which arises far back in the orbit).

The ophthalmic artery supplies all the muscles of the orbit from within the cone of muscle, supplies the lacrimal gland by branches from the artery accompanying the lacrimal nerve and supplies the eye. This last is by two sets of vessels. The **central artery** supplies the optic nerve and retina, while the **posterior ciliary arteries** pierce the sclera to enter the choroid coat of the eye. There is no anastomosis between the two sets of vessels. *The central artery is an end artery.* It is the first, the smallest and by far the *most important branch* of the ophthalmic. It slants gradually through the meningeal coverings of the optic nerve and enters the inferomedial part of the nerve halfway between the optic canal and the eye. **Anterior ciliary arteries**, from the muscular branches to the recti, pierce the anterior part of the eye.

Ophthalmic veins

Two ophthalmic veins drain the orbit. The **superior ophthalmic vein** commences above the medial palpebral ligament and passes back above the optic nerve with the ophthalmic artery. It receives tributaries that

correspond in the main with the branches of the ophthalmic artery, and it communicates at its commencement with the angular vein. It drains directly into the cavernous sinus. The **inferior ophthalmic vein** commences in front of the orbit (communicating over the infraorbital margin with tributaries of the facial vein) and runs back within the cone of muscles. It communicates with the superior ophthalmic vein and drains through the inferior orbital fissure into the pterygoid plexus.

Lymphatics

The lymphatics of the orbit drain through the eyelids and cheeks to the preauricular and parotid lymph nodes and so to the upper group of deep cervical nodes (p. 522).

MOVEMENTS OF THE EYES

Normal binocular vision depends on the properly coordinated activity of the 12 muscles that move the two eyes. All the ocular muscles have a high proportion of nerve fibres in relation to muscle fibres and also an unusually high proportion of muscle spindles. Although the movements produced by individual muscles (described above) are common questions for students, it is their combined activities that really matter. In terms of overall function, it is helpful to remember that three of the rectus muscles—medial, superior and inferior—are concerned with turning the eye in (not just the medial rectus as might be expected), and that the lateral rectus and the two obliques turn it out.

The actions of the *medial* and *lateral recti* are simple. Each lies in a horizontal plane and turns the eye *in* or *out* respectively. There are no secondary movements.

The actions of the superior and inferior recti and obliques are more complex. Each is inserted beyond the coronal equator, and the line of pull passes medial to the axis of rotation of the eye. Thus the *superior rectus* turns the eye *up and in*, and in the *inferior oblique* turns it *up and out* (Fig. 6.50); combined they produce a *vertical upward* movement, for their medial and lateral components cancel each other out. Similarly the *inferior rectus* turns the eye *down and in*, the *superior oblique* *down and out*; combined they turn it *vertically down*. Pure up and down movement is produced by one rectus acting with its oppositely-named oblique (superior rectus and inferior oblique, inferior rectus and superior oblique).

In order to look straight ahead, the tendencies of opposing muscles to turn the eye up or down, in or out, must cancel each other out. However, when considering individual muscle actions, it is important to note

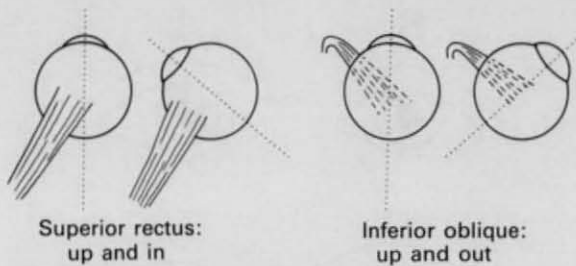


Fig. 6.50 Actions of the right superior rectus and inferior oblique muscles.

that the *elevating* action of the *inferior* oblique and *depressing* action of the *superior* oblique only become effective *when the eye is turned in*; the more the eye is turned out, the less is their contribution to the up or down movement. Similarly the elevating and depressing actions of the superior and inferior recti are most effective when the eye is turned out.

The obliquity of pull of the superior and inferior recti and obliques produces a certain amount of *torsion* or wheel rotation of the eye. Thus, as viewed by an observer from the front, 12 o'clock on the right cornea rotates to 1 o'clock (*intorsion*) produced by the superior rectus and oblique, or to 11 o'clock (*extorsion*) produced by the inferior rectus and oblique. This results in *obliquity* of the *false image* when one of these muscles is paralysed.

Control of conjugate gaze

Moving the eyes from side to side implies turning one eye in and the other out; this is *conjugate horizontal gaze* or deviation and, if looking to the left for example, depends essentially on the co-ordinated activity of the left lateral rectus and right medial rectus. The neural pathways (Fig. 6.51) involve fibres from the visual cortex to the frontal eye field in the middle frontal gyrus, from which fibres pass to a region of the reticular formation of the opposite side adjacent to the abducent nucleus in the pons and variously known as the *para-abducent nucleus* or *pontine paramedian reticular formation*. From here some fibres pass to the abducent nucleus of the same side, so activating the lateral rectus of one eye; the other fibres cross the midline to join the medial longitudinal bundle and run to the part of the oculomotor nucleus that controls the medial rectus of the other eye.

There must be similar controls for up-and-down movements but the pathways have not been so clearly defined; they appear to include the pretectal region of the midbrain.

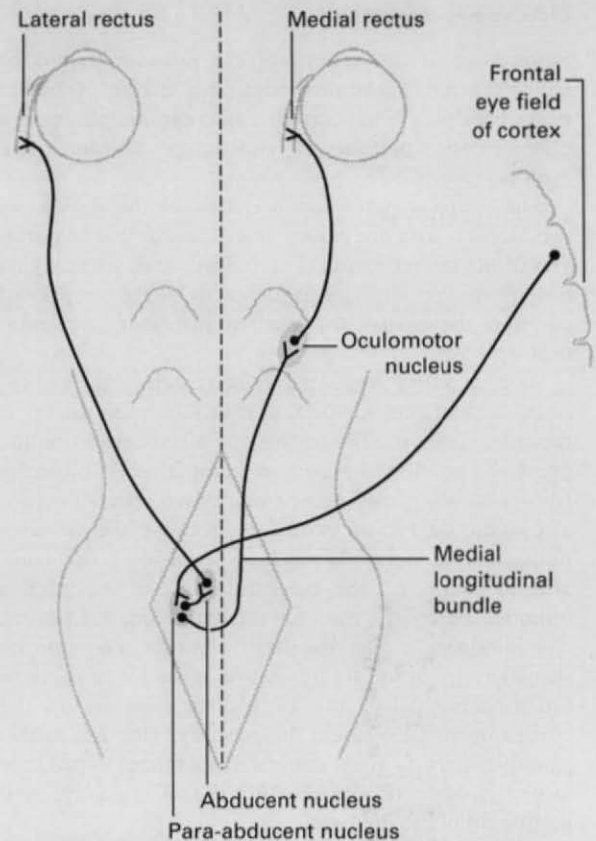


Fig. 6.51 Pathway for conjugate gaze. The para-abducent nucleus (pontine paramedian reticular formation) projects to the abducent nucleus of the same side and the oculomotor nucleus of the opposite side.

Nystagmus and vestibulo-ocular reflexes

Nystagmus is an involuntary oscillatory movement of the eyes, which may be either horizontal (the commonest), vertical or rotatory. There are alternating slow and fast phases, usually with a slow drifting movement away from the direction of gaze and a quick jerk towards the direction of gaze. The direction of the nystagmus is named from the direction of the quick movement. It is most commonly seen in diseases of the labyrinth or eighth nerve, but also occurs in cerebellar disease and brainstem lesions such as multiple sclerosis. The induction of nystagmus by irrigating the external acoustic meatus with warm and cool water (*caloric tests* — p. 642) constitutes the **vestibulo-ocular reflex**. The use of iced water in an unconscious patient should induce conjugate deviation of the eyes to the same side. The absence of this reflex is one of the criteria of brainstem death (p. 616).

Ocular nerve paralyses

Knowledge of the actions of eye muscles should be supplemented by summarizing the effects of ocular nerve paralyses. Each complete nerve lesion produces a characteristic pattern of strabismus (squint) and diplopia (Fig. 6.52).

The simplest nerve lesion is that of the *sixth nerve* (abducent). The eye *cannot look outwards* due to paralysis of the lateral rectus (Fig. 6.52A) and, when trying to look straight ahead, it is turned in by the unopposed action of the medial, superior and inferior recti (oculomotor nerve).

With a *fourth nerve* paralysis (trochlear), the eye *cannot look downwards* as far as it should when the eye is turned in (Fig. 6.52B) because of the superior oblique paralysis, so that the patient complains of difficulty (diplopia) when reading or going down stairs. There is also some degree of extorsion, because the superior oblique which normally produces intorsion is not available to counteract the extorting effect of the inferior oblique. To compensate for the extorsion, the patient characteristically tilts the head towards the opposite shoulder, in order to bring (for example in a right fourth nerve palsy) the 11 o'clock position on the cornea up to 12 o'clock; the good eye (the left in this example) uses its intact control mechanisms to produce intorsion, so compensating for the affected eye and getting rid of the diplopia.

With a *third nerve* lesion (oculomotor), the most obvious feature is *ptosis* of the upper lid due to paralysis of the levator (but beware of the patient who has deliberately closed an eye to get rid of the diplopia due to a sixth nerve lesion!). When the lid is manually lifted up, the eye is seen to be looking *down and out* (Fig. 6.52C) due to the unopposed actions of the lateral rectus (sixth nerve) and superior oblique (fourth nerve). The eye cannot be turned up, in or further down due to paralysis of the superior, medial and inferior recti, but on looking outwards the diplopia will disappear because the lateral rectus (sixth nerve) is acting normally. The pupil is dilated and does not react to light or on accommodation, due to interruption of the parasympathetic fibres that run in the oculomotor nerve (p. 518, though the consensual reflex in the opposite eye is preserved).

STRUCTURE OF THE EYE

The eye contains the light-sensitive retina and, like a camera, it is provided with a lens system for focusing images (the cornea, lens and refractive media) and with means of controlling the amount of light admitted (the iris diaphragm). Like a camera, its inside is black to

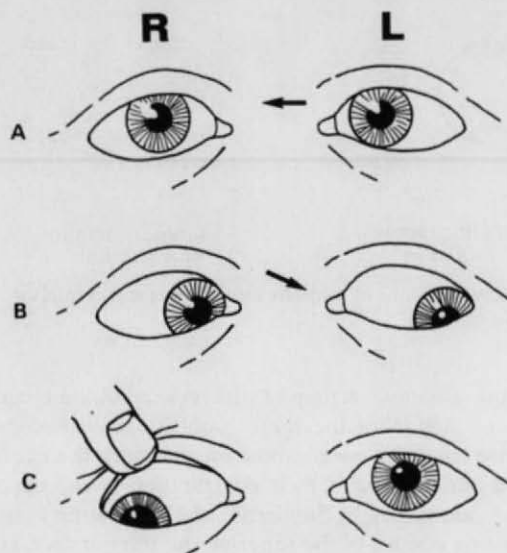


Fig. 6.52 Position of the right eye in right ocular nerve paralyses, when attempting to look in the direction of the arrow in **A** and **B**, and looking forward in **C**. **A** Abducent nerve. **B** Trochlear nerve. **C** Oculomotor nerve.

prevent internal reflections. The relatively large area behind the lens is occupied by the vitreous body. In front of the lens is the small area filled by aqueous humour and incompletely divided into anterior and posterior chambers by the iris. The space bounded by the inner margin of the iris is the pupil.

The wall of the eye, enclosing the refractive media, is made up of three coats. The outer coat is *fibrous* and consists of the sclera and cornea; a *vascular* coat (the choroid, ciliary body and iris) intervenes between this and the innermost *nervous* coat (the retina). The sclera can be regarded as a cup-like expansion of the dural sheath of the optic nerve. The choroid, similarly, is an expansion of the arachnoid and pia, the retina being an expansion of the brain substance of the optic nerve.

Throughout this section consult Figure 6.55.

Fibrous coat

The **sclera** is a dense feltwork of fibrous tissue comprising the posterior five-sixths of the eyeball. The interlacing fibres run mostly anteroposteriorly and coronally. The sclera is opaque (the 'white' of the eye). It is thinnest at the entrance of the optic nerve, whose perforating fibres give it a sieve-like appearance, the **lamina cribrosa**. If a sustained increase of intraocular pressure occurs (chronic glaucoma) the lamina cribrosa yields and bulges posteriorly ('cupping' of the disc).

The *sheath of dura mater* around the optic nerve blends with the sclera. The sclera receives the insertions of the ocular muscles. It is pierced obliquely by the *ciliary nerves and arteries* around the entrance of the optic nerve, and by the *venae vorticosae* (the choroid veins) just behind the coronal equator. The anterior ciliary arteries (from muscular branches to the recti) perforate the sclera near the corneoscleral junction.

The sclera is almost avascular. The bulbar conjunctiva is attached to it by loose connective tissue (episclera) which is vascular; engorgement of its vessels produces a circumcorneal injection indicative of inflammation within the eye.

The **sinus venosus sclerae (canal of Schlemm)** circumscribes the corneoscleral junction, at the periphery of the anterior chamber. Its posteromedial end is bounded by (what appears in sections as) a prominent triangular projection of tissue, the *scleral spur*, to which are attached the radial fibres of the ciliary muscle (see below). The endothelial lining of the canal is in contact with the mesothelium of the spaces of the pectinate ligament (see below). The endothelial cells contain giant vesicles that transport aqueous humour from the anterior chamber into the canal. The canal is connected with anterior scleral veins, into which it drains. Normally the outflowing aqueous humour fills the canal, but if the veins are obstructed the canal fills with regurgitated blood (like the thoracic duct at its opening into the brachiocephalic vein).

The **cornea** is continuous with the sclera (Fig. 6.55), with the difference that its laminae of fibrous tissue are transparent instead of opaque white. It bulges forward from the sclera at the *corneoscleral junction* or *limbus*, being the segment of a smaller sphere. It occupies the anterior one-sixth of the eye and is completely avascular. At the limbus the conjunctival epithelium becomes continuous with the **corneal epithelium**, which is a very regular stratified squamous type of about five layers of cells. It is separated from the corneal stroma by the *anterior limiting layer* (Bowman's membrane), a homogenous layer with scattered collagen fibrils and much ground substance. Dryness of the epithelium sets off the blinking reflex, which lubricates the epithelium with tears (p. 508).

The **corneal stroma** or substantia propria consists of over 200 lamellae of collagen fibrils, with fibroblasts (sometimes called *corneal corpuscles*) scattered among the lamellae. The transparency is due to the precise lattice arrangement of its lamellae embedded in a ground substance whose water content is carefully controlled by transport from the stroma through the endothelial cell layer to the anterior chamber. If pathological vascularity or oedema occurs, the part becomes opaque. The normal

lack of vascularity (and of lymph vessels) accounts for the success of corneal grafts, which are thus not invaded by T lymphocytes. The inner surface of the stroma lies against a thick basal lamina, the *posterior limiting layer* (Descemet's membrane), which is produced by the overlying single layer of **corneal endothelium** (an unusual use of the word endothelium, which is otherwise confined to the lining of blood vessels and lymphatics). Peripherally in the angle of the anterior chamber, the *iridocorneal angle*, the stroma is continued as a sponge-work of fibres, the *pectinate ligament*, attached to the sclera, ciliary muscle and the front of the iris.

The cornea receives its nutrition from scleral vessels at the limbus, by diffusion from the aqueous humour and by the direct uptake of oxygen from the air at the surface of the epithelium.

Nerve supply. The cornea is supplied mainly by the *short ciliary nerves* from the ciliary ganglion (p. 513), with a few fibres running in the *long ciliary nerves*. For the protection of this small but vitally important area of the body surface, an intact **corneal reflex** is essential. The reflex is elicited clinically by the gentlest touching of the cornea (not the conjunctiva) with a point of cotton wool; both eyes should shut. The pathway is via the trigeminal ganglion (no synapse) to the main sensory nucleus (synapse) whence impulses pass by way of neurons of the reticular formation to reach both facial nerve nuclei and so stimulate both orbicularis oculi to close the lids on both sides.

Vascular coat

The intermediate coat of the eye, frequently known as the **uveal tract**, consists of a continuum of vascular tissue which is made up of the choroid, the ciliary body and iris.

The **choroid** is a thin, pigmented layer that lines the posterior part of the sclera, from which it can readily be stripped up. It is brown in man, black in many animals. It ends anteriorly at the *ora serrata*, where it merges into the ciliary body (Fig. 6.55). It is perforated by the optic nerve, to which it is firmly attached. Its *choriocapillary layer*, which has large fenestrated capillaries, provides nutrition for the rods and cones of the retina, to whose pigmented layer the choroid adheres firmly. The veins collect into four or five large *venae vorticosae*, which pass symmetrically through the sclera just behind the equator.

The **ciliary body** extends from the corneoscleral junction backwards rather more than halfway to the equator (i.e. for about 6 mm). It lies as a flat ring applied to the inner surface of the sclera. The ring is thickest around its internal anterior circumference (at

the corneoscleral junction) whence it thins out to its external posterior circumference, here to blend at the ora serrata with the anterior margin of the choroid.

Being thicker in front and thinner behind, the ciliary body appears triangular in section. The two long sides of the triangle are in contact with the sclera externally (or anteriorly) and the vitreous body internally (or posteriorly). The periphery of the iris is attached halfway along the short anterior side of the triangle. The scleral surface of the ciliary body contains the ciliary muscle. The vitreous surface of the ciliary body appears smooth and black peripherally, where it is continuous with the choroid at the ora serrata, but further forward this surface is projected into about seventy ridges which radiate for some 2 mm from the anterior margin. The ridges are the *ciliary processes*; they are white, but the grooves between them are black like the peripheral part of the vitreous surface. They lie in reciprocal grooves on the anterior surface of the vitreous body. Their central ends are free and rounded.

The **ciliary muscle** consists of smooth muscle; its function is to focus the lens for near vision. It has two sets of fibres, radial and circular. The *radial fibres* are attached to the periphery of Descemet's membrane and to the scleral spur at the corneoscleral junction. The circular fibres lie within the anterior part of the radial fibres as a sphincter. Both sets of fibres relax the suspensory ligament, allowing the lens to bulge and focus near objects on the retina. Both parts of the muscle are supplied from the accessory (Edinger–Westphal) part of the oculomotor nucleus in the midbrain, by fibres which relay in the ciliary ganglion and enter the eye in the short ciliary nerves.

The muscle has no opponent — elastic recoil of the suprachoroid lamina tenses the suspensory ligament as the muscle relaxes, and this tension in the ligament flattens the lens.

The **iris** is attached at its periphery to the middle of the anterior surface of the ciliary body; peripheral to this attachment the ciliary body itself and a narrow rim of sclera form the iridocorneal angle of the anterior chamber. From its peripheral attachment the iris is pushed slightly forwards, in the form of very low cone, by contact with the anterior convexity of the lens. The iris is perforated centrally by the pupil, the varying size of which (see below) controls the amount of light entering the eye.

The main bulk of the iris is made up of blood vessels and the loose connective tissue between them. The connective tissue contains a variable number of pigment cells, which determine the *colour of the iris*. If they are absent the iris is blue in colour by diffusion of light in front of the black posterior surface. As the

pigment cells increase in number the iris colour becomes increasingly darker. The colour of the pigment, too, varies in different individuals.

The **sphincter pupillae** is a well-developed circular band of smooth muscle lying posteriorly at the margin of the pupil. It is supplied (see below), like the ciliary muscle, from the accessory (Edinger–Westphal) part of the oculomotor nucleus. The **dilator pupillae** is an ill-defined sheet of radial fibres (smooth muscle) extending over the back of the iris from the ciliary body to the pupil margin behind the sphincter. It is supplied by the cervical sympathetic. The preganglionic cells lie in T1 segment of the spinal cord. Both sphincter and dilator muscles (but not the mesodermal ciliary muscle) are derived from neural ectoderm.

The front of the iris is covered with a single layer of flattened cells continued from the back of the cornea. The back of the iris is covered by two layers of deeply pigmented cells which, continuous with those of the ciliary body, extend to the inner margin of the pupil.

Control of the pupil and reflexes

The size of the pupil depends on the interplay between the sphincter innervated by parasympathetic fibres and the dilator which receives a sympathetic supply. The parasympathetic pathway can be illustrated by considering the pupillary light reflexes and the accommodation–convergence reflex, while sympathetic control (or rather the lack of it) is exemplified by studying the background to Horner's syndrome.

Shine a light into one eye, and the pupil of that eye constricts; this is the **direct pupillary light reflex**. The pupil of the other eye also constricts; this is the *indirect* or **consensual light reflex**. The neural pathway is as follows (Fig. 6.53). Some fibres of the optic tract bypass the lateral geniculate body by running in the superior brachium to reach the midbrain at the level of the superior colliculus and enter the pretectal nucleus. From there the cell bodies send their axons to the Edinger–Westphal nucleus, from which fibres reach the ciliary ganglion via the oculomotor nerve and its branch to the inferior oblique. The short ciliary nerves from the ganglion supply the sphincter pupillae. Because the pretectal nucleus sends fibres to the Edinger–Westphal nucleus, not only of its own side but to the opposite side as well, *both* pupils will constrict. But there is another reason: the partial crossing of the fibres of one optic nerve in the optic chiasma also ensures that both pretectal nuclei are stimulated.

Pathological studies indicate that in the main oculomotor nerve trunk the pupillary fibres lie on the *dorsal* surface of the nerve and have a blood supply from vessels

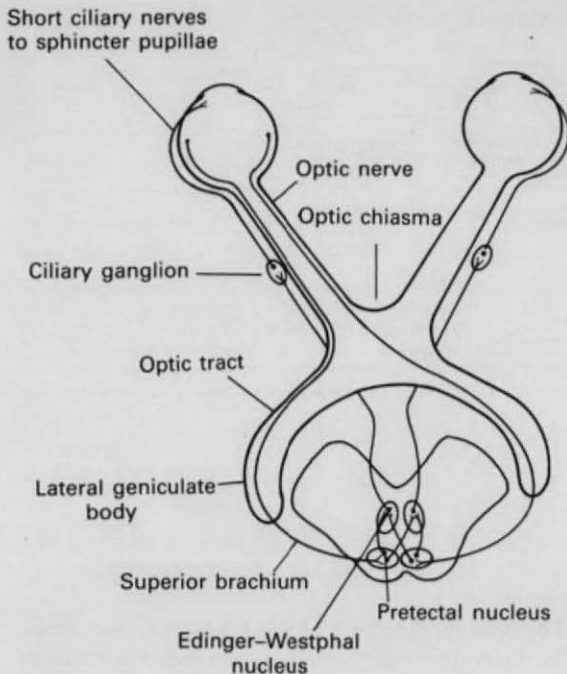


Fig. 6.53 Pathway for pupillary light reflexes.

of the nerve *sheath*, not from those of the nerve trunk. Thus these fibres may be affected by pressure (e.g. from an aneurysm of the posterior communicating artery) but not by infarction of the nerve trunk (as in diabetes).

The eye automatically focuses and converges for near vision, and this change in lens curvature is accompanied by pupillary constriction to sharpen the focus. These three components—accommodation, convergence and pupillary constriction—constitute the **accommodation-convergence reflex**, sometimes called the **near reflex**. The changes accompany conscious vision: they involve cortical as well as subcortical pathways. From the visual cortex an association bundle reaches the frontal eye field of the middle frontal gyrus. Cell bodies in this cortex send their efferent fibres via the anterior limb of the internal capsule to the oculomotor nucleus including the Edinger-Westphal part, whence by ciliary ganglion relay they activate the ciliary muscle and the sphincter pupillae. Contraction of the ciliary muscle releases tension on the suspensory ligament of the lens, so allowing the lens by its own elasticity to thicken and focus for near vision. Thus the accommodation pathway reaches the Edinger-Westphal nucleus without passing through the pretectal nucleus—a major difference from the pupillary light pathway

described above. Accompanying the accommodation changes, the medial rectus muscle of each eye contracts to provide the necessary convergence for near vision.

The *Argyll Robertson pupil*, which constricts on accommodation but not to light, is usually explained by suggesting a lesion in the dorsal part of the midbrain involving the pair of pretectal nuclei, but there is doubt about this because it fails to explain why the pupil is small.

The **sympathetic path** to the pupil is a very long one compared to the parasympathetic route, because the sympathetic outflow from the spinal cord does not occur above T1 level (Fig. 6.54). From cells in the posterolateral part of the hypothalamus (whose cortical control is uncertain), fibres run down through the lateral part of the brainstem near the spinal lemniscus to lateral horn cells in T1 segment of the cord. Preganglionic fibres enter the sympathetic trunk via the white ramus communicans of T1 nerve and pass up to the superior cervical ganglion. From there postganglionic fibres accompany the internal carotid artery into the skull and cavernous sinus, leaving the artery to join the ophthalmic nerve and become distributed to the eye by the nasociliary and then the long ciliary branches.

Damage to any of the above fibres can interrupt this pathway. Thus such things as vascular lesions of the cortex or brainstem and affections of the sympathetic trunk by cervical rib, carcinoma of the lung, thyroid or oesophagus may give rise to **Horner's syndrome**. The characteristic features include *slight constriction of the pupil* (due to unopposed parasympathetic activity and really a failure of dilatation) but which still reacts to light and accommodation, *partial ptosis* (due to paralysis of the visceral muscle part of levator palpebrae) and *reduction of sweating* on the forehead or larger area of the head (unless the lesion is above the superior cervical ganglion, when there is no loss of sweating).

Nervous coat

The **retina** is the delicate innermost membrane of the eye. It lies attached to the basal lamina of the choroid, and its inner surface is in contact with the vitreous body. The light-sensitive area ends abruptly, halfway between equator and corneoscleral junction, at a dentate line, the **ora serrata**. Forward of this a thin insensitive layer passes on in continuity as the ciliary part of the retina and the pigmented epithelium on the back of the iris. At the entrance of the optic nerve is a circular pale area, 1.5 mm in diameter; this is the **optic disc** (Fig. 6.56). It overlies the lamina cribrosa of the sclera. The optic disc is excavated to a variable degree, producing the **physiological cup**. There are no rods

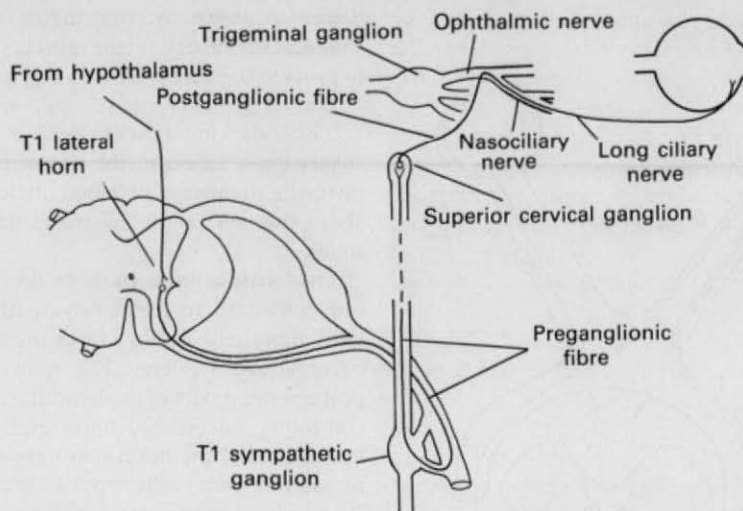


Fig. 6.54 Sympathetic pathway to the pupil.

or cones in the optic disc, hence it is insensitive to light — the '**blind spot**'. The disc and whole surrounding area of the back of the eye as seen with the ophthalmoscope constitute the **fundus** of the eye.

At the posterior pole of the eye (3 mm lateral to the optic disc) is a shallow depression of comparable size to the disc; it is completely free of blood vessels and is yellowish in colour, hence called the **macula lutea** (it would lie just beyond the right-hand margin of Fig. 6.56). In the centre of the macula is a shallow pit, the **fovea centralis**. This is the thinnest part of the retina. It is the area of the most acute vision, for here the nerve cells of the retina are pushed aside and the rods disappear. Only cones lie in the fovea.

The outer layer of the retina consists of a single layer of pigmented epithelial cells firmly attached to the lamina vitrea of the choroid. Next to this layer lie the light receptors (the rods and cones), forming a layer less firmly attached to the pigment cells, so that in detachment of the retina the pigment cells remain in position while the rods and cones, with the other layers of the retina, become displaced inwards from them.

The physiological arrangement of the nervous elements is very similar to that in any other sensory pathway (e.g. in the spinal cord). From the sense receptor, the first neuron has its cell body peripherally placed (in the retina this is the bipolar cell). It leads by synapse to the second neuron (in the retina this is the ganglion cell) whose axon passes to the thalamus (in this case the lateral geniculate body) whence, after relay, the third neuron leads through the retrolentiform part of the internal capsule to the visual cortex (Fig. 7.8, p. 588).

The light receptors are of two kinds, rods and cones. Only the **rods** contain visual purple; they are the more primitive type of light receptor. They do not register colour, but are sensitive to dim light (*scotopic vision*). The periphery of the retina contains rods only, the fovea centralis none at all. Eighty rods by their bipolar cells share one ganglion cell (i.e. one axon to the lateral geniculate body). They are of low threshold; 80 rods together 'whisper up the line' to the thalamus and cortex. The **cones** have a higher threshold (*photopic-vision*) and they register colour. Cones alone occupy the fovea centralis. Beyond this they share equally with the rods, but they fall short of the periphery of the retina. Each cone is connected to a single ganglion cell — alone it 'shouts up the line' to the thalamus and cortex.

A detailed account of the microscopic anatomy of the 10 layers of the retina is beyond the scope of this book. For the student of general anatomy the following is a brief summary; those who need detailed descriptions will consult textbooks of histology. Suffice it to say here that the most striking features of a typical microscopic section of the retina are three groups of nuclei. The group nearest the outer part of the retina is of small closely-packed nuclei (layer 4, which must not be mistaken for lymphocytes!) that belong to the *rod and cone cells*, which otherwise mostly occupy layer 2. Further in is layer 6 whose nuclei belong to the *bipolar cells*, and nearest the inner surface are the more scattered large nuclei of the *ganglion cells* (layer 8) whose axons form the optic nerve fibres. The functional implications of these groups have been considered above.

Blood supply. The *central artery* of the retina passes

through the lamina cribrosa within the optic nerve and in the optic disc divides into an upper and lower branch (Fig. 6.56). Each gives off nasal and temporal branches. The upper and lower temporal branches curve up and down respectively to clear the macula lutea. The branches of the central artery are end arteries. They supply the neurons (bipolar and ganglion cells) of the retina. The light receptors (rods and cones and their nuclei in the outer nuclear layer) are supplied by diffusion from the capillaries of the choroid. The *retinal veins* run with the branches of the central artery. The central vein leaves via the optic disc and emerges from the optic nerve and its coverings to join the superior ophthalmic vein. Perivascular lymph spaces exist in the retina, but it is doubtful if lymphatic vessels emerge from the eye.

Development. The retina is developed from a hollow out-growth, the *optic vesicle*, which protrudes from the cerebral vesicle. The optic vesicle becomes invaginated to form the *optic cup*, consisting of two layers of cells. The outer layer differentiates to form the pigment cell layer. The inner layer forms the remaining layers of the retina with the rods and cones outermost (next to the pigment cells). The ganglion cells and their

axons are innermost; light has therefore to pass through them to activate the receptors.

REFRACTING MEDIA

Most of the refraction of light takes place at the *junction of air and corneal epithelium*. Beyond the cornea light passes through the aqueous humour, the lens and vitreous body to reach the retina.

The **aqueous humour** lies between the back of the cornea and the front of the lens. The space is divided by the iris into *anterior* and *posterior chambers*, which communicate with each other through the pupil. The aqueous fluid is secreted by the ciliary body and diffuses from the capillaries of the ciliary processes in the posterior chamber and passes through the pupil into the anterior chamber, from which it drains into the canal of Schlemm (Fig. 6.55).

The **anterior chamber** is limited peripherally by the angle between the sclera (just beyond the corneoscleral junction) and the ciliary body (beyond the peripheral attachment of the iris). The angle contains the sponge-like pectinate ligament and is often called the *filtration*

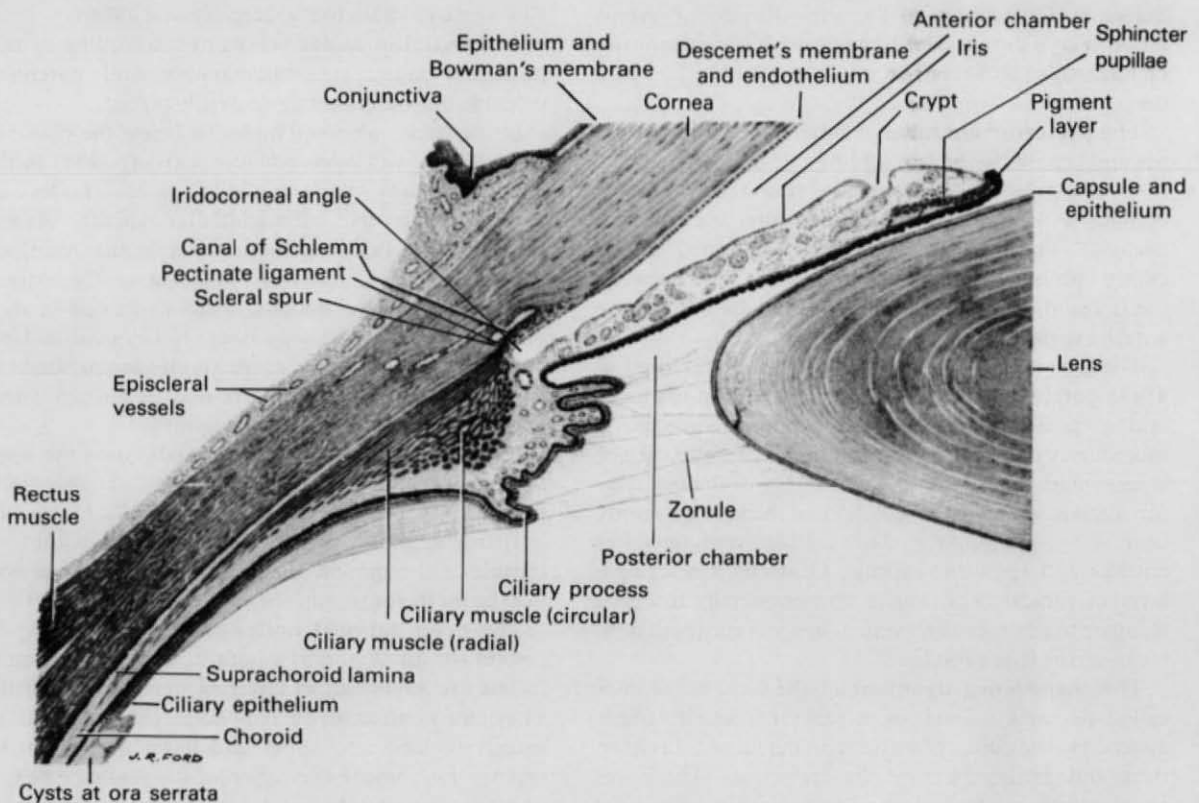


Fig. 6.55 Section through the eye in the region of the corneoscleral junction.

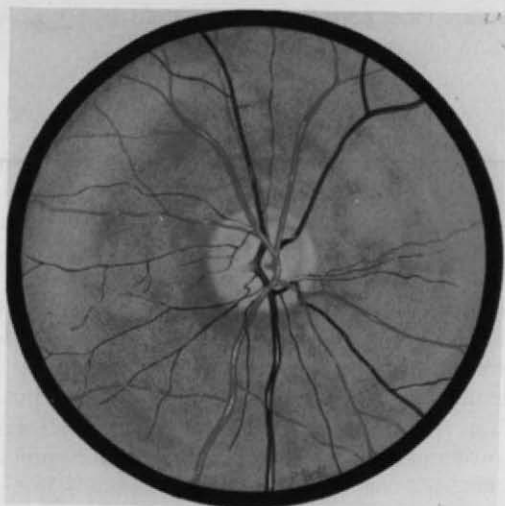


Fig. 6.56 Fundus of the left eye, as seen with the ophthalmoscope. The upper and lower branches of the central artery of the retina (the paler vessels) emerge from the centre of the disc, and are accompanied by the (darker) retinal veins.

angle: aqueous humour drains through it into the canal of Schlemm. Obliteration of the angle therefore prevents absorption of the aqueous humour, with consequent rise of intraocular tension. The anterior chamber is 3 mm deep centrally.

The **posterior chamber** is bounded in front by the iris and behind by the lens and its suspensory ligament. It is triangular in cross-section (pupil and lens in contact with each other forming the apex of the triangle). The base of this triangle is formed by the ciliary processes. Aqueous humour lies between the fibres of the suspensory ligament as far back as the anterior surface of the vitreous.

The **lens** is a transparent biconvex body enclosed in a transparent elastic capsule. It is 10 mm in diameter and its posterior surface, resting on the vitreous, is more highly convex than the anterior. The latter surface is in contact with the pupillary margin of the iris. The *lens capsule* is homogeneous and is thickest anteriorly near the circumference. The *capsular epithelium* lies anteriorly, deep to the capsule. Centrally it is a single layer of cubical cells, but more peripherally the cells elongate to produce *fibrils* which, by their accumulation, make up the lens substance.

The **suspensory ligament** of the lens, sometimes called the *ciliary zonule*, is a series of delicate fibrils attached to the ciliary processes and the furrows between them and, further back, to the ora serrata. The fibres pass centrally to attach themselves to the lens, mostly in front of, but a few behind, the circumference. In the rest

position they hold the lens flattened under tension; when relaxed by contraction of the ciliary muscle, elasticity of the lens causes its anterior surface to bulge, so thickening it (as in accommodation — p. 519).

The **vitreous body** is a colourless, jelly-like mass which occupies the posterior four-fifths of the eyeball. It is enclosed in the delicate homogeneous *hyaloid membrane*. It is indented in front by the posterior convexity of the lens and, beyond this, has radial furrows reciprocal with the ciliary processes. It is traversed from the front towards the optic disc by the tiny hyaloid canal, the site of the embryonic hyaloid artery. The vitreous body is attached to the optic disc and just in front of the ora serrata; elsewhere it lies free, in contact with the retina.

PART 16

LYMPH DRAINAGE OF HEAD AND NECK

Lymph drainage is described with each organ, but here the various groups of nodes are summarized to give an overall picture of their distribution in the head and neck. They consist of numerous outlying nodes which all eventually drain to the deep cervical group.

The **outlying nodes** are named according to their positions; many are subcutaneous and potentially palpable but others are more deeply placed.

In the neck, *submental* nodes lie below the chin near the midline, with *submandibular* nodes (p. 435) farther laterally below the mandible (some nodes are embedded in the submandibular gland). *Anterior cervical* nodes lie along the anterior jugular vein, and *superficial cervical* nodes are adjacent to the external jugular vein. In the midline of the neck, one or more nodes may lie in the *infrahyoid*, *prelaryngeal* and *pretracheal* positions. Other deeper nodes are paratracheal and retropharyngeal, and there may be a single *lingual* node on the outer surface of hyoglossus.

In the head, there are *occipital* nodes over the upper attachment of trapezius and *posterior auricular* nodes over the upper part of sternocleidomastoid. *Prauricular* or parotid nodes are both outside and within the capsule of the parotid gland, and a single *buccal* node may lie on the outer surface of buccinator.

The **deep cervical nodes** are scattered along the carotid sheath (Fig. 6.57), both in front of and behind it, and are largely under cover of sternocleidomastoid. They are connected by lymphatic channels and are usually divided into upper and lower groups. In the *upper group*, some in the region of the posterior belly of digastric are palpable and include the *jugulodigastric nodes*, while those in the lower group near the tendon of

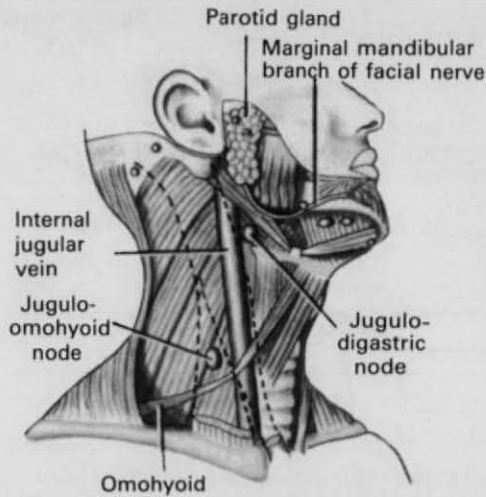


Fig. 6.57 Jugulodigastric and jugulo-omohyoid nodes of the deep cervical chain. Sternocleidomastoid is indicated in dotted outline.

omohyoid are the *jugulo-omohyoid nodes*. The lowest nodes constitute the *supraclavicular group*. The upper nodes tend to receive lymph from the back of the tongue, tonsil, ear, nose and sinuses and the upper pharynx and larynx, while the lower group receives from the face and anterior part of the scalp, anterior part of the tongue, lower pharynx and larynx, thyroid gland and mediastinum (and on the left side perhaps from the stomach). Because of widespread communications, the lymphatic spread of disease may extend well beyond the groups originally involved.

Lymph from the lower end of the deep cervical chain is collected into the **jugular lymph trunk**. The left trunk usually drains into the thoracic duct, although it may join the internal jugular or subclavian veins. The right jugular trunk reaches the right lymphatic duct or the right brachiocephalic vein.

PART 17

TEMPOROMANDIBULAR JOINT

The **temporomandibular joint** is a synovial joint between the head of the mandible and the mandibular fossa on the under surface of the squamous part of the temporal bone. It is separated into upper and lower cavities by a fibrocartilaginous disc within the joint. Both bone surfaces are covered with a layer of fibrocartilage identical with that of the disc. There is no hyaline cartilage in this joint, so it is an atypical synovial joint. The

articulating surfaces of both bones and of the disc are covered with synovial membrane in the newborn, but with use of the jaws this soon disappears and the membrane is then restricted to a narrow fringe lining the capsule.

The **capsule** is attached high up on the neck of the mandible around the articular margin of the head. It is more spacious above, and is attached anteriorly just in front of the transverse prominence of the articular tubercle (Figs. 8.4, p. 646 and 8.5, p. 651), posteriorly to the squamotympanic fissure, and medially and laterally between these lines. It is lax but strong.

The articular **disc** is attached around its periphery to the inside of the capsule. Anteriorly it is attached near the head of the mandible, and this part of the disc moves forward with the head. Posteriorly it is attached nearer the temporal bone and therefore cannot move forward so freely; but the texture of this posterior part is less dense than elsewhere. The fibres are crinkled (like knitted socks) so that they can elongate and recoil a little. The disc seen in section has an undulating contour which moulds it to the incongruity of the bony surfaces; it is thinnest at the centre, thickest around its edges.

The anterior margin of the disc and adjoining capsule receive the insertion of the upper fibres of the lateral pterygoid.

The **lateral temporomandibular ligament** is a stout band of fibrous tissue passing obliquely down and back from the lower border of the zygomatic arch to the posterior border of the neck and ramus of the mandible. Its deep fibres blend with the capsule (Fig. 6.15). It tightens in retraction of the head of the mandible. It tightens also in that protraction of the head which accompanies opening of the jaw. The mandibular fossa is an ovoid concavity, like a deep spoon, and the ligament is most relaxed in the rest position of the mandible, but is tightened by movements away from the rest position. The head and neck of the mandible move in the fossa like a toggle switch.

The **sphenomandibular ligament**, running between the spine of the sphenoid and the lingula of the mandible (p. 560), is included as an accessory ligament of the joint because its lower attachment is at the axis of rotation of the mandible, and it remains constant in length and tension in all positions of the mandible (p. 524).

The nerve supply of the joint is from the auriculo-temporal nerve, with a few fibres from the nerve to masseter (Hilton's law).

Stability

The joint is much more stable with the teeth in occlusion than when the jaw is open.

In **occlusion** the teeth themselves stabilize the mandible on the maxilla and no strain is thrown on the joint when an upward blow is received on the mandible. In the occluded position apart from the stabilizing effect of the teeth, forward movement of the condyle is discouraged by the prominence of the articular tubercle and by contraction of the posterior fibres of temporalis, which backward movement is prevented by the obliquity of the fibres of the lateral ligament and by contraction of the lateral pterygoid.

In the **open position** the joint is less stable. As well as rotating, the condyle lies forward on the slope of the articular tubercle. Backward dislocation towards the tympanic plate is opposed by the obliquity of the fibres of the lateral ligament and by contraction of the lateral pterygoid. Forward dislocation is opposed by the slope of the articular tubercle, by the tension of the lateral ligament and by contraction of the masseter, temporalis and medial pterygoid muscles. In the open position there is little to prevent upward dislocation through the thin plate of bone roofing in the mandibular fossa; the injury is very rare because a blow on the drooping chin usually either closes or more fully opens the mouth of the recipient.

Forward dislocation is the commonest form of displacement. Reduction is prevented by spasm of the posterior deep fibres of the masseter (p. 455). These fibres by their spasm hold the *dislocated* jaw open, because the condyle is so far forward that they pass down *behind* its axis of rotation. The spasm must be overcome (with or without an anaesthetic) before the anterior dislocation can be reduced. Anterior dislocation readily occurs in the edentulous. It is easily reduced; the joint is less stable because the increased elevation of the edentulous mandible permanently elongates the lateral ligament.

Movements

In the rest position there is a 3–4 mm separation of the upper and lower teeth. Mandibular movements may be considered in three groupings: protraction and retraction (also called protrusion and retrusion), depression and elevation (commonly called opening and closing the jaws), and side-to-side (grinding) movements. The group of muscles commonly classified as the muscles of mastication — temporalis, masseter and medial and lateral pterygoids — play major roles in these movements; others taking part can be called accessory muscles of mastication.

In *protraction* (an uncommon movement, as when deliberately jutting the chin forwards without opening the mouth, in a gesture of defiance) the lateral pterygoids

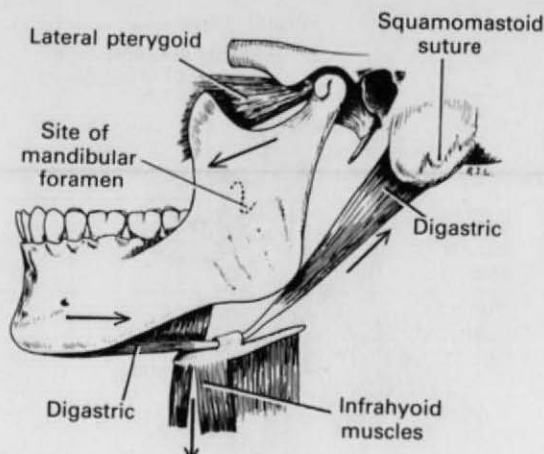


Fig. 6.58 Mandible and muscle actions. The mandible is rotated by the digastric and lateral pterygoid muscles; the infrahyoid muscles tether the pulley for the digastric tendon. The axis of movement passes through the mandibular foramina.

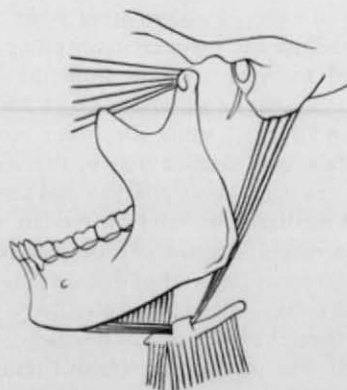


Fig. 6.59 Mandibular movement for opening the mouth wide. Compare with Figure 6.58, and note that continued contraction of the lateral pterygoid pulls the head of the mandible out of the mandibular fossa.

pull the heads of the mandible and the articular discs forwards along the surface of the articular tubercles. The normal position is restored (*retraction*) by the lowest horizontal fibres of temporalis — the fibres that hook downwards over the root of the zygomatic process.

In *depression* of the mandible (opening the jaw), there is not only a hinge movement of the head below the disc but also gliding movement of the disc on the articular tubercle. The heads are pulled forwards by the lateral pterygoids and the chin is pulled down and back by the digastric muscles (Fig. 6.59). The axis of movement

passes through the mandibular foramina; the sphenomandibular ligaments act like the ropes of a swing, keeping the lingulae at the entrance to the foramina at a constant distance from the base of the skull. This is what happens when opening the mouth wide, but it is important to note that in an unconscious patient the mouth may drop passively open by hinge movement only in the lower compartment of the joint; the tongue swings back, narrows the oropharynx and obstructs the airway, with snoring or choking.

Elevation of the mandible (closing the jaw) is produced by the masseters, medial pterygoids and temporalis muscles. Thus of the four muscles of mastication, the lateral pterygoid is the 'odd man out': it helps to open the jaw, whereas the others close it.

Side-to-side movements are the result of medial and lateral pterygoid activity on one side, alternating with similar activity on the other side.

In *anterior dislocation*, spasm of the masseter holds the head of the mandible tight against the articular tubercle; for reduction the operator's thumbs must first press *downwards* on the molar teeth to overcome this before guiding the head back into its fossa.

Movements of the floor of the mouth

The floor of the mouth is essentially the two mylohyoid muscles, whose midline raphe and posterior fibres are attached to the body of the hyoid bone. Contraction of the muscle flattens out the angle between its two halves, and hyoid bone and raphe are drawn upwards, elevating the floor.

Geniohyoid and stylohyoid determine by their relative lengths the anteroposterior position of the hyoid bone. They lengthen or shorten the floor of the mouth, the mylohyoid raphe being passively lengthened or shortened, like a concertina. Both muscles slope down to the hyoid bone; hence their opposing contractions elevate the floor of the mouth.

The elevators of the floor (mylohyoid, geniohyoid and stylohyoid) are opposed by the infrahyoid strap muscles. The resultant of the opposing contractions of these muscles determines the vertical and anteroposterior position of the hyoid bone (and therefore the state of the floor of the mouth and the position of the larynx). In ordinary movements these muscles play no part in depressing the mandible. In very forced movements of depression they may act as accessory muscles to assist the digastric. In very forced depression even the platysma may join in the tug of war on the mandible — watch an exhausted runner nearing the finishing post.

Swallowing. The first or voluntary stage of swallowing (deglutition) consists in passing the bolus

through the oropharyngeal isthmus, and is discussed with tongue movements (p. 483): The back of the tongue is *pushed back* by compression of the contracting mylohyoid on the front part of the tongue musculature, and it is *pulled back* and up by styloglossus after the bolus has passed (Fig. 6.42).

The second or involuntary stage commences as the bolus enters the oropharynx, but the pharynx is *already elevated* before the bolus arrives.

The *larynx* is suspended from the hyoid bone by membrane and muscle and elevates with the floor of the mouth. In addition it possesses its own elevators. The medial muscle of the styloid apparatus (stylopharyngeus), assisted by salpingopharyngeus and palatopharyngeus and the inferior constrictor, draws up the larynx and pharynx. This elevation *precedes* elevation of the hyoid bone. Elevation of the hyoid bone in the first stage of swallowing is accompanied by further elevation of the larynx and pharynx. The laryngeal inlet, elevated beneath the protecting shelf of the overhanging epiglottis, is closed by contraction of the aryepiglottic muscles, and respiration is suspended. The epiglottis itself is inverted by the passing bolus, and closes like a lid over the larynx. It recovers its normal position by its own elastic recoil; its framework consists of elastic cartilage (Fig. 6.42). Note that a large semisolid bolus separates the inverted epiglottis from the posterior wall of the pharynx. A smaller and more liquid bolus is separated by the inverted epiglottis into two lateral food channels, seen in an anteroposterior cineradiograph (Fig. 6.43); the inverted epiglottis is in contact with the pharyngeal wall.

The sequence of swallowing for the bolus is obviously first stage in the mouth, second stage in the pharynx. But the sequence of muscle contraction is not the same. The sequence is (1) larynx and pharynx move up to the hyoid bone (Fig. 6.42), *then* (2) larynx and pharynx and hyoid move up together, *then* (3) larynx and pharynx and hyoid move down together, *then* (4) larynx and pharynx move down from the hyoid bone.

The *soft palate* is elevated against the projecting shelf of Passavant's ridge, sealing off the nasopharynx. This opens the auditory tube.

With nose and larynx thus sealed off the bolus has nowhere to go but down the pharynx. The bolus is much hastened in its descent by the elevation of the pharynx to receive it, like a snake darting upwards open-mouthed for its prey, and by a peristaltic wave of contraction that passes behind it down the pharyngeal constrictors and into the upper part of the oesophagus. Beyond this level it is safe from regurgitation, and the laryngeal inlet opens to resume respiration. There is no discernible change in the peristaltic wave as it proceeds

from the skeletal-muscle part of the oesophagus into the visceral-muscle part, at a speed of 3–5 cm per second.

PART 18

EAR

The **ear**, which houses the peripheral parts of the auditory and vestibular apparatus, is descriptively divided into the external, middle and internal ear. The external ear consists of the auricle or pinna and the external acoustic meatus, at the medial end of which lies the tympanic membrane, separating the external ear from the middle ear. The middle ear or tympanic cavity (tympanum) is an irregular space in the temporal bone containing the auditory ossicles (malleus, incus and stapes) and air that communicates with the nasopharynx by the auditory tube. By its medial wall the middle ear adjoins the inner ear, which is composed of the osseous labyrinth, another space within the temporal bone, inside which is the membranous labyrinth containing the auditory and vestibular nerve receptors.

EXTERNAL EAR

The **auricle** or pinna has a skeleton of resilient yellow elastic cartilage which is thrown into folds. The folds give the auricle its characteristic shape. The cartilage is covered on both surfaces with adherent hairy skin; it does not extend into the lobule of the ear. The lobule is a tag of skin containing soft fibrofatty tissue; it is easily pierced for earrings. The cartilage of the auricle is prolonged inwards in tubular fashion as the cartilaginous part of the external acoustic meatus, whose attachment to bone stabilizes the auricle in position. *Intrinsic muscles* in the auricle act as sphincter and dilator mechanisms of the external meatus in lower animals, but they are vestigial and functionless in man. *Extrinsic muscles* move the auricle in lower animals, but in man are without function. They lie anterior, superior and posterior to the auricle and all are supplied by the facial nerve.

The **external acoustic meatus** is a sinuous tube nearly 3 cm in length; it is straightened for introduction of an otoscope by pulling the auricle upwards and backwards. Due to the obliquity of the tympanic membrane at the deep end of the meatus, separating it from the tympanic cavity, its anteroinferior wall is longest and its posterosuperior wall shortest. Its outer third is cartilage, its inner two-thirds bone; in both zones the skin is firmly adherent.

The bony part is formed by the tympanic part of the temporal bone, C-shaped in cross-section, the gap in the C being applied to the under surface of the squamous and petrous parts. The cartilaginous portion is likewise C-shaped; the gap is filled with fibrous tissue attached to the periosteum of the squamous bone. Hairs and sebaceous glands abound in the cartilaginous part. Here also are the *ceruminous glands*, long coiled tubules like modified sweat glands, which secrete a yellowish-brown wax. The meatus is narrowest at the isthmus, a few millimetres from the membrane.

Blood supply. The auricle and external meatus are mainly supplied by the posterior auricular and superficial temporal arteries, with the deeper part of the meatus receiving the deep auricular artery (from the maxillary) which enters the meatus through the squamotympanic fissure. There are corresponding veins.

Lymph drainage. To occipital, preauricular and superficial cervical nodes.

Nerve supply. The main cutaneous nerves are the great auricular and auriculotemporal nerves, with perhaps unexpected contributions from the vagus and facial nerves. The great auricular (p. 427) supplies the whole of the cranial surface of the auricle (C2, with a little overlap from the lesser occipital at the top) and the lower part of the lateral surface. The auriculotemporal (p. 452) supplies the upper part of the lateral surface and most of the meatal skin, but some twigs from the auricular branch of the vagus (p. 464) and the facial nerve via the tympanic plexus (p. 529) spill off from the tympanic membrane (see below) to posterior meatal skin, with vagal supply extending over the mastoid process.

MIDDLE EAR

The **middle ear** is an air-space in the temporal bone (Figs 6.60 and 6.61). It contains the three auditory ossicles whose purpose is to transmit sound vibrations from the tympanic membrane in its lateral wall to the inner ear which forms its medial wall. The cavity of the middle ear, the tympanic cavity or tympanum, is really the intermediate portion of a blind diverticulum from the respiratory mucous membrane of the nasopharynx. From front to back the diverticulum consists of the *auditory tube*, the *tympanic cavity*, and the *mastoid antrum and air cells*, and is formed by the interposition of part of the second pharyngeal pouch into the first pouch. It therefore has a mixed nerve supply (pp. 39 and 529).

Tympanic cavity

The **tympanic cavity**, about 15 mm in diameter, is the

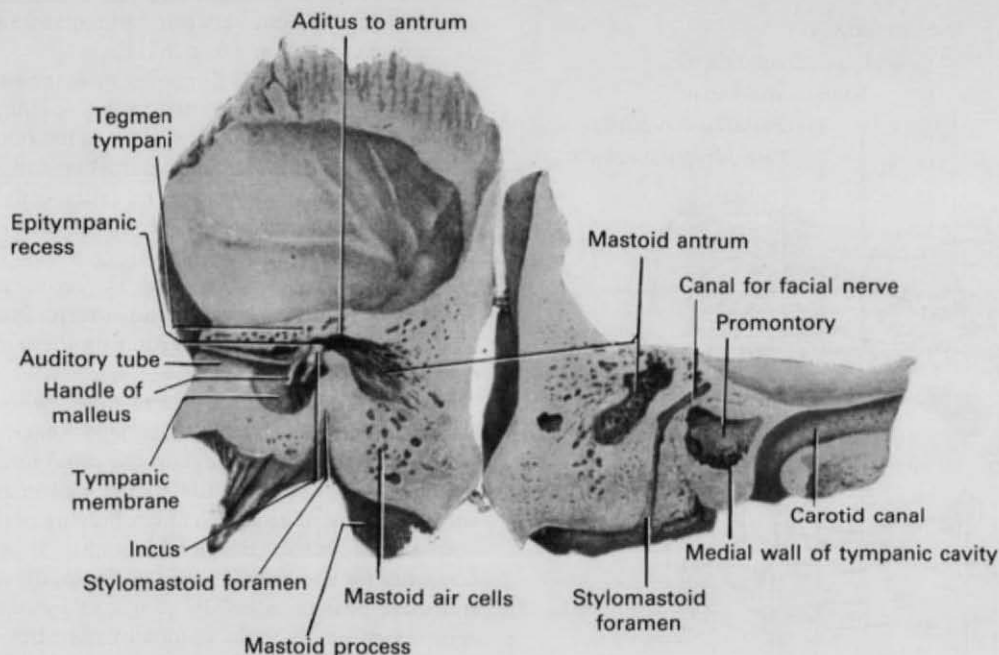


Fig. 6.60 Right temporal bone sectioned obliquely along the axis of the petrous part, with the medial part turned back (to the left). The slight inequality of the two cut surfaces results from the loss of bone in the saw cut.

shape of a biconcave lens, tilted to the plane of the tympanic membrane (see below). Its lateral wall is largely occupied by the tympanic membrane, which extends upwards for 10 mm from the floor and bulges inwards to within a millimetre or two of the medial wall. Above the membrane the temporal bone is hollowed out into the epitympanic recess.

The **tympanic membrane** is a thin fibrous structure covered externally with a thin layer of stratified squamous epithelium and internally with low columnar epithelium. The framework consists of collagen fibres in a superficial (lateral) radial set and a deep (medial) circumferential set. The membrane is circular, 1 cm in diameter, and lies obliquely at 55° with the external acoustic meatus, facing downwards and forwards as well as laterally. It is concave towards the meatus. At the depth of the concavity is a small depression, the *umbo*, produced by the handle of the malleus. When the drum is illuminated for inspection, the concavity of the membrane produces a 'cone of light' radiating from the umbo over the anteroinferior quadrant. The handle of the malleus is firmly attached to the inner surface of the membrane. From the lateral process of the malleus two thickened fibrous folds (malleolar folds) diverge up to the margins of the tympanic bone; between them the small upper

segment of the membrane is lax (*pars flaccida*, Shrapnell's membrane). This part is crossed internally by the chorda tympani, which may be seen here by a well-illuminated otoscope. The rest of the membrane, the main part, is the *pars tensa*.

The tympanic membrane is thickened at its circumference and slotted into a groove in the tympanic plate at the site of the tympanic ring of the fetus (p. 48). It is held tense by the inward pull on the tensor tympani muscle. Its tension is affected by difference of pressure in the tympanic cavity and external meatus in cases of auditory tube obstruction.

Blood supply. By the deep auricular artery (maxillary) on the meatal side, and on the mucosal side the stylomastoid artery (posterior auricular), which forms a circular anastomosis with the tympanic branch of the maxillary round the margin of the membrane.

Nerve supply. On the meatal surface by the auriculo-temporal nerve, unexpectedly supplemented by the facial and vagus nerves (p. 526), with the tympanic branch of the glossopharyngeal nerve (tympanic plexus, p. 529) on the mucosal surface.

The **medial wall** of the tympanic cavity (which is also the lateral wall of the internal ear) has as its most prominent feature the *promontory* (Fig. 6.61), due to the first turn of the cochlea and indented with fine grooves

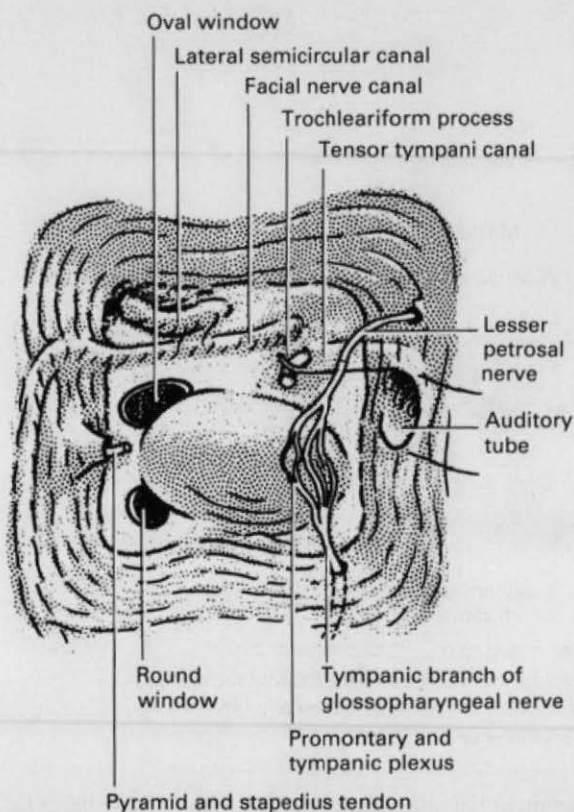


Fig. 6.61 Medial wall of the right middle ear, showing the promontory and related features.

by the tympanic plexus. Above it is the (horizontal) canal for the facial nerve, and immediately above that is the (horizontal) bulge due to the lateral semicircular canal. Above and behind the promontory is the oval window (fenestra vestibuli), closed in life by the foot-piece of the stapes. Below and behind the promontory is the round window (fenestra cochleae), closed in life by the fibrous secondary tympanic membrane. Just below the anterior end of the facial nerve canal is the trochleariform process (formerly cochleariform), a funnel-shaped projection from the posterior end of the canal for the tensor tympani in the anterior wall.

The **roof** of the tympanum is the *tegmen tympani*, a laminar projection of petrous bone that roofs in also the canal for the tensor tympani and the tympanic antrum. Above it the temporal lobe lies in the middle cranial fossa.

The **floor** is a thin plate of bone above the jugular fossa. At the anterior end is the internal opening of the tympanic canaliculus, where the tympanic branch of the glossopharyngeal nerve enters (the external opening

is on the ridge of bone between the jugular foramen and the carotid canal, Fig. 8.5, p. 651).

The **anterior wall** is shortened by approximation of roof and floor. It is perforated by the openings of two canals: the lower and larger of these is the bony part of the auditory tube, the upper and smaller is the canal for the tensor tympani muscle. The latter canal extends somewhat backwards before opening on the medial wall as the processus trochleariformis (Fig. 6.61). The lower part of this wall is perforated by caroticotympanic branches of the internal carotid artery. Sympathetic fibres from the carotid plexus run with them to join the tympanic plexus.

The **posterior wall** is deficient above, where there is an aperture, the *aditus*, which leads back into the tympanic antrum. The ridge of the canal for the facial nerve passes back along the medial wall of the aditus and above this ridge is the convex bulging of the lateral semicircular canal. Below the aditus is a shallow concavity for the short process of the incus, and lower still there projects a hollow cone, the *pyramid*, whose apex is perforated by the tendon of stapedius. Close to the posterior margin of the tympanic membrane is the tiny posterior canaliculus for the chorda tympani.

The **auditory ossicles** form by synovial joints a bony chain for transmission of vibrations from the tympanic membrane to the internal ear. The malleus and incus are developed from the proximal end of the first arch cartilage (Fig. 1.30, p. 38), but the stapes comes from the second arch (Fig. 1.31, p. 38). Formed in hyaline cartilage, they all begin to ossify in the twelfth week, and at this stage the ossicles are already almost adult size.

The **malleus** is shaped like a round-headed club. There is a constriction, the neck, between head and handle. The convex head lies in the epitympanic recess (Fig. 6.60). Its posterior surface has an articular facet for the incus. The narrow neck lies against the pars flaccida of the tympanic membrane. The chorda tympani crosses medial to the neck. The handle projects somewhat backwards down to the umbo; its upper end has a projection, the lateral process. The two form a lateral concavity moulded to the medial convexity of the tympanic membrane; the periosteum of lateral process and handle is firmly fixed to the fibrous layer of the membrane. The malleal folds are attached to the apex of the lateral process. The anterior process is slender; it is embedded in the fibres of the anterior ligament.

The **incus** has a relatively large body (Fig. 6.60) and two slender processes or limbs. The body is rounded and laterally compressed. It lies in the epitympanic recess and articulates anteriorly with the head of the malleus. The short limb projects backwards to lie in a

shallow fossa in the posterior wall just below the aditus. The *long limb* projects down into the cavity of the middle ear, just behind and parallel with the handle of the malleus. Its tip hooks medially and is bulbous — the lentiform nodule — for articulation with the stapes.

The **stapes** has a small *head* showing a concave facet for articulation with the lentiform nodule. A narrower *neck* diverges into slender anterior and posterior *limbs*, the former shorter and less curved than the latter. The limbs are attached to the *base* (or footpiece); a delicate obturator membrane, clothed with mucosa, fills the space between them. The base is oval and fits into the oval window (Fig. 6.63); the two are united by circumferential ligamentous fibres of elastic tissue.

The **synovial joints** of the ossicles are the *incudomalleolar joint*, between the head of the malleus and the body of the incus, and the *incudostapedial joint*, between the long limb of the incus and the head of the stapes. Their capsules and accessory ligaments, including some which anchor the ossicles in the epitympanic recess, contain a high proportion of elastic fibres. The *anterior ligament* from the anterior process of the malleus passes through the squamotympanic fissure to the spine of the sphenoid; its downward enlargement is the sphenomandibular ligament. The attachment of the footpiece of the stapes to the margins of the oval window is the *tympanostapedial syndesmosis*.

The **muscles of the ossicles** are two, one for the malleus, developed with it from the first pharyngeal arch, and one for the stapes, developed with it from the second arch. They are thus innervated by mandibular and facial nerves respectively. Their function is to damp down overvibration from low-pitched sound waves.

The **tensor tympani** arises from and occupies the upper semicanal of the *musculotubular canal*, separated by a thin bony septum from the lower semicanal which is the bony part of the auditory tube (Fig. 8.8, p. 658). The slender muscle ends in a round tendon which bends around the processus trochleariformis (at the posterior end of the bony septum), passes across the cavity of the middle ear and is inserted into the upper end of the handle of the malleus (Fig. 6.60). Its nerve of supply from the mandibular nerve runs in the nerve to the medial pterygoid, from which it passes near the otic ganglion to reach the muscle. The cell bodies lie in the motor nucleus of the trigeminal nerve (in the pons); there is no relay in the otic ganglion. Contraction of the muscle draws the handle of the malleus inwards, making the drum more highly concave and therefore more tense. It has no opponent — elastic recoil restores the status quo as the muscle relaxes.

The **stapedius** arises from the interior of the hollow pyramid. Its tendon emerges from the apex of the

pyramid and is inserted into the back of the neck of the stapes. The muscle is supplied from the facial nerve by a branch given off in the facial (stylomastoid) canal. Its action is to retract the neck of the stapes, thus tilting the footpiece in the oval window; the anterior margin of the footpiece cants towards the tympanic cavity. It has no opponent; elastic recoil replaces the footpiece.

The thin **mucous membrane** of the middle ear, continuous with that of the auditory tube and mastoid antrum, adheres to all the structures enumerated above — the walls, ossicles, ligaments and muscles. Because of all these irregularities, certain pouches are produced, particularly in the epitympanic recess alongside the ligaments of the malleus. The lining epithelium is columnar and in parts ciliated, but the cells may show considerable variation in height and may even be squamous.

Blood supply

Numerous very small arteries enter the middle ear, mostly from branches of the external carotid. The largest are the anterior tympanic from the maxillary (through the squamotympanic fissure), and the stylomastoid from the posterior auricular or occipital (through the stylomastoid foramen). Veins pass through the squamotympanic fissure to the pterygoid plexus or through the petrous bone to the superior petrosal sinus; thrombophlebitis from suppuration in the middle ear may involve veins of the temporal lobe, leading to meningitis or cerebral abscess.

Lymph drainage

To parotid, retropharyngeal and upper deep cervical nodes.

Nerve supply

The mucous membrane of the middle ear is supplied by branches of the **tympanic plexus**. This is mainly formed by the *tympanic branch* of the *glossopharyngeal nerve* (Jacobson's nerve), which enters the petrous bone through the tympanic canaliculus between the jugular foramen and the carotid canal (Fig. 8.5, p. 651), and runs up to the promontory, on whose surface it forms a fine plexiform network (Fig. 6.61). It is joined by *sympathetic* fibres from the internal carotid nerve which enter the tympanic cavity through the wall of the carotid canal with branches of the caroticotympanic artery. Branches from the plexus supply sensory and vasomotor fibres to the mucous membrane of the cavity and of the auditory tube; the sensory fibres have their cell bodies in the glossopharyngeal ganglia, and the

postganglionic sympathetic fibres have come from the superior cervical ganglion. A few sensory tympanic branches of the facial nerve probably also join the plexus by piercing the petrous bone from the geniculate ganglion (see below) where they have their cell bodies. These fibres are embryological remnants from the second pharyngeal pouch (p. 39). Apart from supplying mucosa, they may extend to the tympanic membrane and external meatus, thus explaining the occurrence of vesicles there in 'facial herpes'.

Since the middle ear and the external ear (p. 526) are supplied by branches of the trigeminal, facial, glossopharyngeal and vagus nerves, pain in the ear (otalgia) may be referred from many other areas supplied by these nerves, especially the teeth, posterior part of the tongue, pharynx and larynx.

The plexus gives off the **lesser petrosal nerve**. This contains preganglionic parasympathetic fibres from the inferior salivary nucleus, destined to supply the parotid gland via the otic ganglion. The fibres enter the plexus with the glossopharyngeal tympanic branch. The nerve leaves the middle ear through a canaliculus in the anterior wall above the auditory tube and runs a short course in the middle cranial fossa, emerging through a small hiatus lateral to the greater petrosal nerve (Fig. 8.8, p. 658) and reaching the otic ganglion by the foramen ovale (or if present the petrosal foramen, Fig. 6.18).

Facial nerve and the ear

The **facial nerve** itself is not within the middle ear cavity but passes through the petrous bone from the internal acoustic meatus to the stylomastoid foramen in three directions, laterally, posteriorly and downwards, in that order. First the main trunk of the nerve runs *laterally* from the internal acoustic meatus with the nervus intermedius, which contains the parasympathetic fibres for the pterygopalatine and submandibular ganglia (Fig. 1.25, p. 34), and also taste fibres from the anterior part of the tongue which have run in the chorda tympani (see below). The two parts of the facial nerve here lie above the vestibule, with the cochlea in front and the semicircular canals behind. The nervus intermedius now joins the main nerve at the geniculate ganglion. The greater petrosal nerve passes forwards from the ganglion through a canal in the petrous bone and emerges from a hiatus into the middle cranial fossa, which it leaves through the foramen lacerum to become part of the nerve of the pterygoid canal (p. 468).

The facial nerve now passes *backwards* from the ganglion in the canal which raises the ridge on the medial wall of the tympanic cavity *above* the promontory and

below the prominence of the lateral semicircular canal (Fig. 6.61); here branches perforate the bone to enter the tympanic plexus. Finally the nerve passes *downwards* medial to the aditus to the antrum and emerges from the stylomastoid foramen. The nerve to stapedius and the chorda tympani leave this part of the nerve.

The **chorda tympani** is a mixed visceral nerve, containing taste fibres from the tongue (cell bodies in the geniculate ganglion) and secretomotor fibres for the salivary glands of the floor of the mouth (cell bodies in the superior salivary nucleus in the pons). At about 6 mm above the stylomastoid foramen the chorda tympani leaves the facial nerve in the facial canal and pierces the posterior wall of the tympanic cavity lateral to the pyramid (Fig. 6.18). It runs forward over the pars flaccida of the tympanic membrane and the neck of the malleus, lying *just beneath the mucous membrane* throughout its course. It passes out of the front of the middle ear at the anterior margin of the tympanic notch, lying between the tympanic part and that part of the tegmen tympani which walls in the canal for the tensor tympani. It emerges from the petrotympanic fissure, grooves the medial side of the spine of the sphenoid, and joins the lingual nerve 2 cm below the base of the skull (p. 462).

AUDITORY TUBE

The **auditory tube** (pharyngotympanic tube, Eustachian tube) connects the nasopharynx by way of the middle ear with the air cavities in the mastoid part of the temporal bone. Over 3 cm long, it slopes from the middle ear forwards and medially at 45° and downwards at 30°. Like the external acoustic meatus it has bony and cartilaginous parts, but the proportions are reversed.

The **bony part**, over 1 cm long, tapers down from the anterior wall of the middle ear to its orifice. This is the narrowest part of the tube, the *isthmus*; it lies posteromedial to the spine of the sphenoid. The bony part perforates the petrous part of the temporal bone as the lower semicanal of the musculotubular canal (Fig. 8.8, p. 658). It is lined with mucoperiosteum, a thin mucous membrane that is densely adherent to a thin periosteum. It is surfaced by columnar epithelium and, like the rest of the bony cavities, it contains no glands. It is kept moist by evaporation.

The **cartilaginous part**, over 2 cm long, joins the bony orifice at the isthmus and is lodged in the groove between the greater wing of the sphenoid and the apex of the petrous part of the temporal bone (Fig. 8.4, p. 646). It is made of elastic cartilage, in two flanges joined above. The posterior is longer than the anterior flange; thus a vertical section through the cartilage

resembles an inverted J (long limb posterior). It enlarges from the isthmus like a trumpet, with its open end greatly expanded, particularly the long posterior limb which forms the *tubal elevation* in the lateral wall of the nasopharynx. The margins of the flange are joined by a sheet of fibrous tissue. The cartilaginous tube thus completed is lined by respiratory mucous membrane with cilia. The cilia beat towards the nasopharynx, thus protecting the middle ear from airborne particles, including bacteria. Loose longitudinal folds of mucous membrane gently occlude the cartilaginous tube in most individuals; the folds are momentarily parted during swallowing.

The **ostium** (opening) of the tube is attached to the back of the medial pterygoid plate just below the skull base. The tubal elevation is made prominent, especially in the young, by lymphoid follicles in the mucous membrane (tubal tonsil) (p. 490). The posterior limb is elongated by the vertical salpingopharyngeal fold, draped over salpingopharyngeus (described on p. 489). Its contraction must move the tubal elevation and so assist in opening the tube. (It is too small to have much effect in elevating the larynx and pharynx.)

The pharyngobasilar fascia is attached to the lower part of the tube; lateral to this the tensor palati arises outside the pharynx, and medial to this the levator palati arises *inside* the pharynx. Both are attached in part to the tube. Swallowing therefore, by pulling on the lower wall, opens the tube and allows equalization of air pressure on the two sides of the tympanic membrane. Air is slowly lost from the middle ear and mastoid cavities by absorption into the capillaries thereof.

Blood supply. From the ascending pharyngeal and middle meningeal arteries. Its veins drain into the pharyngeal plexus.

Lymph drainage. To retropharyngeal lymph nodes.

Nerve supply. By the pharyngeal branch of the pterygopalatine ganglion (maxillary nerve) at the ostium, and the nervus spinosus (meningeal branch of the mandibular nerve) for the cartilaginous part. The bony part is supplied by branches from the tympanic plexus (glossopharyngeal nerve).

MASTOID ANTRUM AND AIR CELLS

The **mastoid (tympanic) antrum** (Fig. 6.60) lies behind the epitympanic recess in the petrous part of the temporal bone. It is connected to the recess by the **aditus**, and is spherical, but its size is very variable; it may be up to 1 cm in diameter. When large it is covered by a thin layer of bone, when small by a thick layer. Its medial wall lies 15 mm deep to the suprameatal triangle

at the posterosuperior margin of the external acoustic meatus. It is roofed in by the tegmen tympani.

During the first year **mastoid air cells** burrow out into the thin plate of bone at the bottom of the sigmoid sinus. Lined with adherent mucoperiosteum they pneumatize the mastoid process and may eventually extend into the petrous bone for a variable distance, even to the tip. Since the upper superficial part of the mastoid process is formed by the squamous temporal overlying the petrous temporal (p. 645), the squamous as well as the petrous parts may contain air cells, often with a plate of bone (called clinically the 'false bottom') separating the cells into upper superficial and lower deep groups.

Blood supply. By the stylomastoid branch of the posterior auricular artery. The veins drain into the mastoid emissary vein, the posterior auricular vein and the sigmoid sinus. Spreading infection can involve these veins in the posterior cranial fossa, leading to sigmoid sinus thrombosis, meningitis, cerebellar or cerebral abscess.

Lymph drainage. To occipital and upper deep cervical nodes.

Nerve supply. From the tympanic plexus.

INTERNAL EAR

Buried within the stony hardness of the petrous bone is the **internal ear**, practically *full adult size at birth*. It consists of an irregularly-shaped cavity, the **osseous labyrinth**, within which lies an irregular fluid-filled sac; the sac is the **membranous labyrinth**, and the fluid it contains is *endolymph*. Because the membranous labyrinth is smaller than the osseous, its walls are not all pressed tightly against the bone but are mostly separated from it by another fluid, *perilymph*. The endolymph and perilymph do not communicate with one another.

The parts of the osseous labyrinth, in order from front to back, are the **cochlear canal** (or *cochlea*), the **vestibule**, and the **semicircular canals** (Figs 6.62 and 6.63; note that illustrations such as these are really casts of the bony cavity). The parts of the membranous labyrinth (Fig. 6.65) are the **cochlear duct** (within the cochlear canal and concerned with hearing), the **utricle** and **sacculle** (within the vestibule and concerned with static balance), and the **semicircular ducts** (within the semicircular canals and concerned with kinetic balance). Do not confuse the *membranous* cochlear and semicircular ducts with the *bony* semicircular and cochlear canals, nor *endolymph*, which is inside the ducts and other membranous parts, with *perilymph*, which is outside the ducts but within the canals and other bony parts.

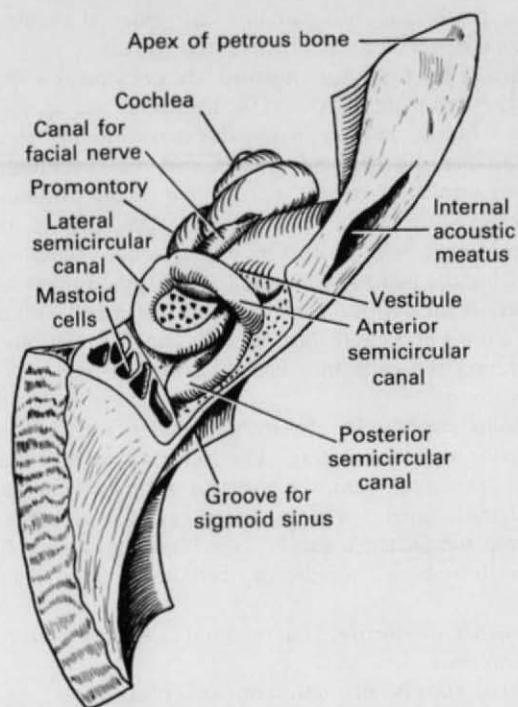


Fig. 6.62 Left osseous labyrinth in the temporal bone, from above. The cochlea is at the front, the vestibule in the middle and the semicircular canals at the back.

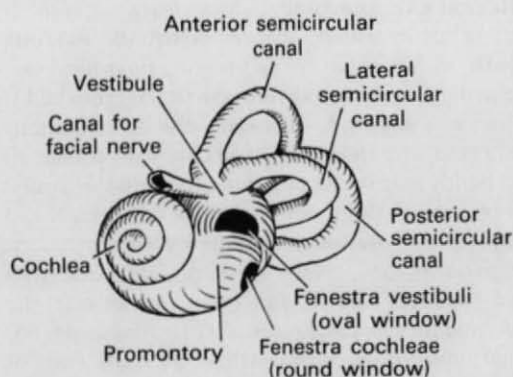


Fig. 6.63 Left osseous labyrinth, from the lateral side.

Osseous labyrinth

The cavity of the osseous labyrinth is lined by endosteum and opens into the medial wall of the middle ear (p. 528) through the *oval window* (closed in life by the footpiece of the *stapes*) and the *round window* (closed in life by the *secondary tympanic membrane*) (Fig. 6.63). It also opens into the posterior cranial fossa through the *aqueduct of the vestibule* (closed in life by the endo-

lymphatic duct — see below, and Fig. 6.94), and the *aqueduct of the cochlea* (Fig. 6.65) through which perilymph is believed to drain into the cerebrospinal fluid. The source of perilymph is uncertain; it may be derived from cerebrospinal fluid or as an ultrafiltrate from perilymphatic blood capillaries.

The **cochlear canal** or cochlea is the cavity in the petrous bone which contains the membranous cochlear duct. The canal is conical in shape, and consists of two and three-quarter spiral turns of a tapering cylindrical canal, like the spiral slide at a fun fair. The bony canal is of greatest calibre at the basal turn; this part projects laterally, producing the promontory on the medial wall of the middle ear (p. 527 and Figs 6.61 and 6.64).

The axial bony stem around which the canal spirals is the **modiolus** (Fig. 6.64). The base of the modiolus lies at the fundus of the internal acoustic meatus and its apex lies across the long axis of the petrous bone, pointing towards the canal for the tensor tympani. The apex of the modiolus is overlaid by the blind extremity of the apical turn of the cochlea, which forms the dome, or *cupola*, of the cochlea.

From the modiolus a shelf of bone projects into the canal, like a thread projecting from a screw. This is the **spiral lamina**; it ends at the apex of the modiolus, beneath the cupola, in a hook-like process, the *hamulus*. Its projection is widest in the basal and narrowest in the apical turn. The membranous **cochlear duct** (Figs 6.64 and 6.65) is attached to the spiral lamina and to the outer bony wall of the canal. It commences blindly at the hamulus and spirals in two and three-quarter turns to its basal extremity, where it is connected by the *ductus reuniens* to the saccule.

The bony canal of the cochlea is thus partitioned by the spiral lamina and the membranous cochlear duct, which contains endolymph. The canal on the apical side of the partition is the **scala vestibuli**, that on the basal side the **scala tympani** (Fig. 6.64); they contain perilymph. At the cupola of the cochlea they communicate with each other around the blind apical extremity of the cochlear duct. This point of communication is the *helicotrema*.

The basal turn of the cochlea sees the termination of the spiral lamina. Here the scala tympani is sealed off into a blind end. There are two holes in this cul-de-sac. One leads laterally into the middle ear — the round window (Fig. 6.63) closed in life by the secondary tympanic membrane. The other is the beginning of a canal, the **aqueduct of the cochlea** (otherwise known as the *perilymphatic duct*), which leads down through the substance of the petrous bone and opens into the *cochlear canaliculus*, below the internal acoustic meatus, in the anterior compartment of the jugular foramen (Fig. 6.94). The aqueduct of the cochlea is patent in life. The arach-

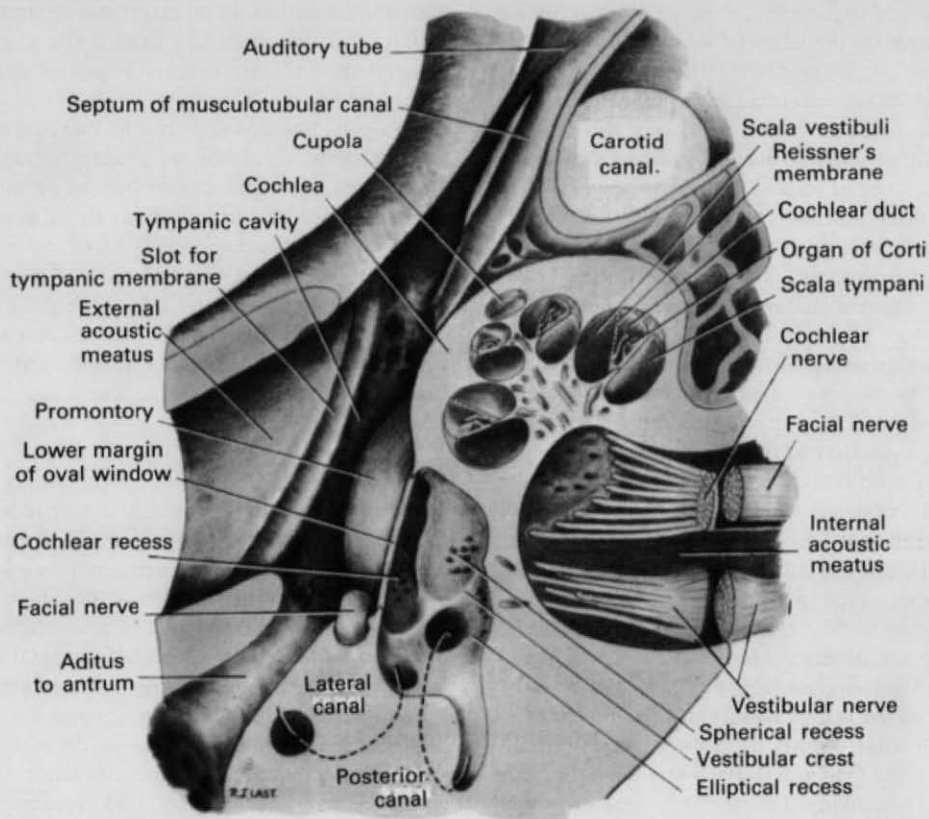


Fig. 6.64 Horizontal section through the left temporal bone, passing through the modiolus and the oval window.

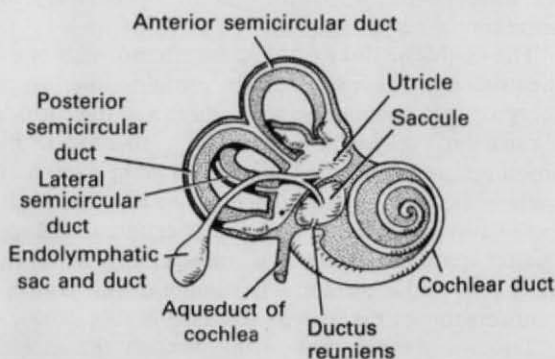


Fig. 6.65 Left membranous labyrinth, from the medial side. The stippled part represents the osseous labyrinth.

noid mater is attached to the margin of its opening, so that perilymph draining down the aqueduct is received into the cerebrospinal fluid in the subarachnoid space.

The modiolus is perforated spirally at its base in the internal acoustic meatus by the branches of the **cochlear nerve** (Fig. 6.64). These run into the

modiolus and fan out spirally towards the base of the spiral lamina, where their bipolar cell bodies lie and form the **spiral ganglion**. This is the counterpart of the posterior root ganglion of a spinal nerve (i.e. it contains the cell bodies of the first neuron of a sensory pathway). The spiral ganglion (cochlear nerve) connects the sound receptors in the spiral organ (see below) with the cochlear nuclei in the brainstem.

The **vestibule** is a hollow in the petrous bone which contains the membranous saccule and utricle (Figs 6.62 and 6.63). It is 3 mm wide and measures 6 mm long and 5 mm high. The scala vestibuli of the cochlea, containing the minute ductus reuniens, opens into the front of the vestibule and the five orifices of the semicircular canals open posteriorly.

The *medial wall* abuts on the internal acoustic meatus. It is excavated into two concavities separated by an oblique curved ridge, the *vestibular crest*. The anterior inferior concavity is the *spherical recess*; it lodges the saccule. The floor is the inferior vestibular area of the internal acoustic meatus; it is perforated by over a dozen minute foramina for the nerves to the saccule from the

inferior division of the vestibular nerve. The posterior superior concavity is the *elliptical recess*, which extends also on the roof of the vestibule. The openings of the anterior and lateral semicircular canals lie behind it. The elliptical recess lodges the utricle. Its floor is the superior vestibular area of the internal acoustic meatus; it is perforated by over a score of minute foramina for passage of nerves to the utricle and the anterior and lateral semicircular ducts. Just posterior to the basal termination of the spiral lamina of the cochlea is a minute pit, the *cochlear recess*, which transmits nerves to the basal end of the membranous duct of the cochlea. These nerves are in series with those passing through the modiolus to the remainder of the cochlear duct. Beneath the cochlear recess, at the lower margin of the elliptical recess, is the opening of the **aqueduct of the vestibule**. This canal is badly named, for no fluid is led along it. It is a minute canal nearly 1 cm long which opens in the posterior cranial fossa on the posterior surface of the petrous bone. It is plugged in life by the endolymphatic duct and a vein; no perilymph can escape through this canal.

The *lateral wall* of the vestibule abuts on the middle ear behind the promontory. Here is the kidney-shaped opening of the oval window (Fig. 6.63), closed in life by the foot-piece of the stapes and its annular ligament.

The **semicircular canals** lie in three planes at right angles to each other (Fig. 6.63). Each is about two-thirds of a circle; in length along the curve they measure about 20 mm. Their calibre is 1 mm except at one end, where each is dilated as the ampulla to a calibre of 2 mm.

The *anterior semicircular canal* (still often called by its older name, superior) is placed in a *vertical plane* across the long axis of the petrous bone, convexity upwards, ampulla laterally. Its convexity produces the *arcuate eminence* on the upper surface of the petrous bone in the middle cranial fossa (p. 654). It lies highest of the three canals, hence its old name, superior.

The *posterior semicircular canal* is placed in a *vertical plane* in the long axis of the petrous bone, convexity backwards, ampulla below. The ampulla is innervated separately by a branch of the vestibular nerve which pierces the *foramen singulare* in the internal acoustic meatus (Fig. 6.95).

The *lateral semicircular canal* is placed 30° off the horizontal plane, convexity backwards, ampulla anteriorly. The ampulla bulges the medial wall of the aditus and epitympanic recess above the facial canal. The lateral semicircular canal lies *horizontal if the head nods 30° forwards*. The canal opens by each end separately into the back of the vestibule. The anterior and posterior canals open separately at their ampullated ends, but their non-ampullated ends fuse into a common canal about 4 mm long. Thus only five openings connect the three canals with the cavity of the vestibule.

The ampullated ends of anterior and lateral canals lie near each other high up, behind the elliptical recess (they share with the utricle the upper division of the vestibular nerve). The ampullated end of the posterior canal opens low down (it has its own branch from the inferior division of the vestibular nerve). The non-ampullated end of the lateral and the common opening of the anterior and posterior canals lie near each other low down towards the medial wall of the vestibule.

It should be noted that anterior and posterior canals, lying across and along the axis of the petrous bone, are each at 45° with the sagittal plane. Thus the posterior canal of one side lies parallel with the anterior canal of the opposite side.

Membranous labyrinth

The **membranous labyrinth** is a reduced replica of the hollow bony labyrinth (Fig. 6.65). It consists of one continuous closed cavity containing *endolymph*. The membranous covering consists of three layers. The outer fibrous layer is vascular and in places adherent to the endosteum of the bony labyrinth forming the *stria vascularis* which produces endolymph. The intermediate layer is homogeneous like a basal lamina and the inner epithelial layer is elaborated in three places into receptors of sound, static balance and kinetic balance. It is supplied by the cochlear (hearing) and vestibular (balance) divisions of the eighth nerve. There is no known reason why hearing and balance are so intimately connected in the same peripheral structure and innervated by the same cranial nerve.

The **cochlear duct** is the spiral anterior part of the membranous labyrinth which contains the sound receptors (do not confuse with *aqueduct* of the cochlea, a canal for perilymph, p. 532). It is attached to the apical surface of the spiral lamina and to the outer bony walls of the cochlea. It commences at a blind extremity in the cupola of the cochlea and after two and three-quarter spiral turns ends in a bulbous extremity in the basal turn of the cochlea. The minute ductus reuniens connects this extremity with the saccule (Fig. 6.65).

Two membranes enclose the duct of the cochlea (Fig. 6.64). The **basilar membrane** extends in the line of the spiral lamina to the outer bony wall of the cochlea. It is widest at the apex (0.4 mm) and narrowest (0.2 mm) at the base of the cochlea. It is over 3 cm long. Throughout its length it supports the spiral organ (see below) and passes from the edge of the spiral lamina to the outer wall of the cochlea.

The *vestibular (Reissner's) membrane* is very delicate: it passes obliquely across the cochlea on the apical side of the basilar membrane. Between these membranes the cochlear duct is triangular in cross-section (Fig. 6.64).

In the **spiral organ** (for precise details of which specialist texts should be consulted) the receptors for hearing, the *sensory hair cells* (formerly the cells of Corti), are lodged in cup-shaped recesses at the tops of the supporting *phalangeal cells* (formerly the cells of Deiters). The receptors are arranged in a single outer row of about 3500 cells, and inner three to five rows of up to 15 000 cells. The 'hairs' are not cilia but modified microvilli, i.e. stereocilia, and are overlaid by the *tectorial membrane*, a sheet of keratin-like protein that projects from beneath the inner attachment of the vestibular membrane. The hair cells are supplied by the dendrites of the 30 000 cells of the *spiral ganglion*.

The mechanism of the organ of Corti is not fully understood. It is probable that sound vibrations are communicated from the perilymph to the endolymph through the delicate vestibular membrane and cause appropriate fibres in the basilar membrane to bulge. The overlying hair cells are thus stimulated.

The **saccul** is a fibrous sac that lies in the lower front part of the vestibule, connected to the basal part of the cochlear duct by the very small ductus reuniens (Fig. 6.65). The **utricle** is a similar sac in the upper and back part of the vestibule and receives the five openings of the three semicircular ducts. The two sacs lie with their adjacent walls in contact; a small duct leads from each and they unite in a Y-shaped manner to form the **endolymphatic duct**. This lies in the aqueduct of the vestibule and projects as a blind diverticulum, the *endolymphatic sac*, beneath the dura mater of the posterior cranial fossa (p. 572). The sac is the site of absorption of endolymph.

The medial wall of the saccul and the floor of the utricle are thickened to form the **maculae**, the areas that contain the *sensory receptors for static balance*. As in the cochlear duct, they are called *hair cells* (with stereocilia), and are here overlaid by the gelatinous *otolithic (statoconial) membrane* which contains particles of calcium carbonate (otoliths or statoconia).

The **semicircular ducts** are only a quarter the calibre of the bony canals except at the **ampullae**, which they almost fill. Each membranous duct is adherent by its *convexity* to the wall of the bony canal in which it lies. The ducts open into five orifices in the back of the utricle inside the elliptical recess.

A transverse crest on the medial surface of each ampulla forms the **crista**, containing the *sensory receptors (hair cells) for kinetic balance*, here overlaid by the gelatinous *cupula*.

The hair cells of the maculae of the utricle and saccul, and the cristae of the semicircular ducts, are stimulated by movements of the otolithic membranes or cupulae respectively in response to head movements, e.g. changes in position, speed of change, etc.

Blood supply of the labyrinth

The *labyrinthine artery* (from the basilar) divides in the internal acoustic meatus into branches which accompany the cochlear and vestibular nerves to the labyrinth. Branches of the stylomastoid artery assist. The veins unite to form a labyrinthine vein which leaves the internal acoustic meatus and joins the inferior petrosal sinus. Various irregular veins penetrate the petrous bone independently to open into the superior petrosal sinus. A small vein lies in each aqueduct; that in the aqueduct of the cochlea joins the inferior petrosal sinus, that in the aqueduct of the vestibule joins the superior petrosal sinus.

Distribution of the eighth nerve

The **cochlear nerve** enters the front of the inferior part of the lamina cribrosa in spiral fashion to reach the organ of hearing (Fig. 6.95). The *lower division* of the **vestibular nerve** supplies the macula of the saccul and, through the foramen singulare, the ampulla of the posterior semicircular duct. The *upper division* of the vestibular nerve supplies the macula of the utricle and the ampullae of the anterior and lateral semicircular ducts and overlaps a little on to the macula of the saccul. The cell bodies of the cochlear fibres lie in the spiral ganglion in the modiolus. The cell bodies of the vestibular fibres lie in the vestibular ganglion in the depths of the internal acoustic meatus.

PART 19

VERTEBRAL COLUMN

The **vertebral column (spine or backbone)** forms the central axis of the skeleton. It supports the skull and gives attachment, by way of the ribs, to the thoracic cage and, by way of this cage, to the pectoral girdle and upper limb. By the pelvic girdle it is strongly united to the lower limbs, which serve the double function of support and propulsion. The great strength of the backbone comes from the size and architecture of the bony elements, the vertebrae, and the ruggedness of the ligaments and muscles that hold them together. This great strength is combined with great flexibility; the backbone is flexible because it has so many joints so close together. Finally, the backbone contains in its cavity the spinal cord, to which it gives great protection from external violence.

The vertebral column is made up of five parts with individual vertebrae peculiar to each: cervical, thoracic, lumbar, sacral and coccygeal.

In the fetus in utero the column lies flexed in its whole extent, like the letter C. This anterior flexion or concavity is the *primary curvature* of the column, and it is retained

throughout life in the thoracic, sacral and coccygeal parts. After birth secondary extension of the column produces the *secondary curvatures* with an anterior convexity (i.e. lordosis) in the cervical and lumbar regions, the former associated with muscular support of the head and the latter with that of the trunk.

As the secondary curvatures develop in the neck and lumbar regions the vertebral column is opened out from its original C-shape, and elongated into a vertical column characterized by gentle sinuous bends. These bends give a certain resilience to the column, but the actual shock-absorbing factors in the spinal column are the intervertebral discs.

Before considering the functional anatomy of the column as a whole (p. 539) certain anatomical details of its several parts should be studied. The short review given here includes sufficient details for understanding the articulations; a fuller account of vertebral osteology begins on page 548.

GENERAL CHARACTERISTICS OF VERTEBRAE

Examine a thoracic vertebra. It consists of a ventral *body* and a dorsal vertebral or neural *arch*; they enclose between them the *vertebral foramen* (not to be confused with the vertebral *canal*, which is the collective name given to the whole series of foramina when the vertebrae are strung together as a column). From the neural arch three processes diverge; in the posterior midline, the spinous process or *spine*, and on either side the *transverse processes*. At the back of the sides of the body are superior and inferior articular facets for articulation with the heads of ribs. That part of the neural arch between spinous process and transverse process is the *lamina*, that between transverse process and body is called the *pedicle*; the pedicles thus connect the rest of the arch to the body. The vertical extent of the pedicle is less than that of the body, to allow room for passage of the spinal nerve through the *intervertebral foramen* between the pedicles of adjacent vertebrae (Fig. 6.68). At the junction of lamina and pedicle (i.e. at the root of the transverse process) are *articular processes*, the *superior and inferior*, which have hyaline cartilage facets for the synovial joints between the neural arches. The direction of the facets conforms with and determines the nature of the movement possible between adjacent vertebrae.

Morphology

The development of a vertebra gives the clue to its morphology. It ossifies in three parts, the *centrum* and the right and left halves of the *neural arch*, and these are the three morphological parts of a vertebra. In the thoracic region *costal elements* develop separately as the

ribs, articulating with the neural arches; but in all other parts of the vertebral column the costal elements become fused to the neural arches and incorporated as morphological parts of the vertebrae.

It should be particularly noted that the morphological *centrum* is not the same thing as the anatomical *body* of a vertebra. Part of the neural arch is incorporated into the body of the vertebra, and the *neurocentral junction* lies anterior to the costal facets on the body; that is, the costal facets on the body lie on the neural arch, and not on the centrum (Fig. 6.77). The term *neural arch* thus has two meanings. In descriptive anatomy it consists of the pedicles and laminae with the processes that project from them. In morphological language it comprises also that part of the body which develops from the neural arch of the embryo — the part with which the costal element articulates.

TYPICAL VERTEBRAE

Examine a mid-cervical, mid-thoracic and mid-lumbar vertebra (Fig. 6.66). Compare and contrast all three. For comparison note that each possesses a body and a neural arch, the latter consisting of pedicles and laminae with the projecting articular processes and the spinous and transverse processes. By contrast note that the cervical vertebra has a *foramen in the transverse process* (formerly called the foramen transversarium and now clumsily named the *vertebrarterial foramen*) and that it has no costal facets. The thoracic vertebra has costal facets, smooth areas that are covered with hyaline cartilage in life. One costal facet lies towards the tip of the transverse process, the others lie as demifacets on the side of the body at its upper and lower margins. The lumbar vertebra has neither a foramen in the transverse process nor costal facets.

These two features, foramen in the transverse process and costal facet, serve to distinguish cervical, thoracic and lumbar vertebrae in all mammals.

Costal elements

Developed in association with each vertebra are **costal elements**. In the thoracic region they develop separately to form the ribs, which articulate with the vertebrae (neural arch) by synovial joints. Elsewhere the costal elements are vestigial and fuse with the neural arches to become incorporated into the adult vertebrae. Beloved of comparative anatomists (and some examiners) they are of little medical interest except where they form cervical ribs (see below).

Cervical vertebrae. The foramen in the transverse process is produced by the costal element. In the typical cervical vertebrae the costal element consists of the *anterior and posterior tubercles* and the intervening costal

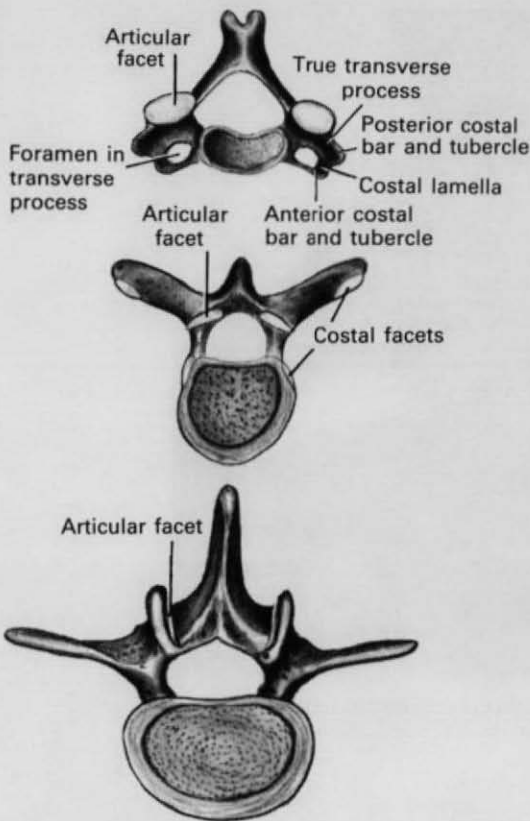


Fig. 6.66 Essential characteristics of cervical, thoracic and lumbar vertebrae.

or *intertubercular lamella* (frequently but wrongly called the costotransverse bar).

A *cervical rib* is due to the elongation of the costal element of C7 vertebra. It presents as either bony elements or fibrous tissue bands, passing down from C7 vertebra to the first rib (Fig. 6.67). The subclavian artery and lowest root (T1) of the brachial plexus become displaced upwards over such structures, and pressure upon them may cause severe symptoms, which usually appear about the age of puberty, when normally the neck elongates and the shoulders droop somewhat. The pressure produced by a thin fibrous band may be more irritating than that due to a smooth bony rib. The presence of a fibrous band may be inferred if the anterior tubercle of C7 vertebra is enlarged. The patient whose radiograph is shown in Figure 6.67 had symptoms on the right side which were due to a fibrous band, and the well-ossified cervical rib on the left side produced no symptoms. When a cervical rib is well developed the brachial plexus is more likely to be prefixed (i.e. its roots are C4, 5, 6, 7 and 8) thus preserving the normal nerve to rib relationship.

Lumbar vertebrae. The so-called *transverse processes* of the lumbar vertebrae are in reality costal elements. The true morphological transverse process is contracted into a small mass of bone which is grooved by the posterior ramus of the spinal nerve. Above the groove lies the *mamillary process* (beside the superior articular facet) and below the groove is found the *accessory tubercle*; both belong to the true transverse element (Fig. 6.78). The costal element may fail to fuse and remain with a synovial joint connecting it to the neural arch; this is a lumbar rib, symptomless and discovered by accident during radiological examination.

Sacrum. The five sacral vertebrae are fused into a single bone and so, too, are the five costal elements. The latter produce the *lateral mass* of the sacrum, lying lateral to the transverse tubercles on the back of the sacrum and extending between the anterior sacral foramina on the front of the bone. The auricular surface for the sacroiliac joint lies wholly on the lateral mass. In morphological terms the pelvis articulates with ribs, not with the centra of vertebrae.

Coccyx. This bone is itself so vestigial that no costal elements can be made out with any certainty. The matter is of no importance.

VERTEBRAL JOINTS

Adjacent vertebrae are held together by strong ligaments and small joints; they allow greater range of movement between the neural arches than between the bodies. The vertebrae articulate between their bodies and between their neural arches. These joints are very different from each other.

Joints between the bodies

The bodies of adjacent vertebrae are held together by the strong intervertebral disc, and by the anterior and posterior longitudinal ligaments.

An **intervertebral disc** is a secondary cartilaginous joint, or symphysis. The upper and lower surfaces of each vertebral body are covered completely by a thin plate of hyaline cartilage. These plates are united by a peripheral ring of fibrous tissue, the **annulus fibrosus**. It consists of concentric laminae, the fibres of which lie at 25°–45° with the bodies of the vertebrae. Alternate layers of the annulus contain fibres lying at right angles to each other. By this means the annulus is able to withstand strain in any direction. Inside the annulus is a bubble of semiliquid gelatinous substance, the **nucleus pulposus**, derived from the embryonic notochord. (The notochord extended originally as far cranially as the sella turcica, but it disappears except in the nucleus pulposus of each intervertebral disc.) The nucleus pulposus in the embryo lies at the centre of the disc. Subsequent growth of the

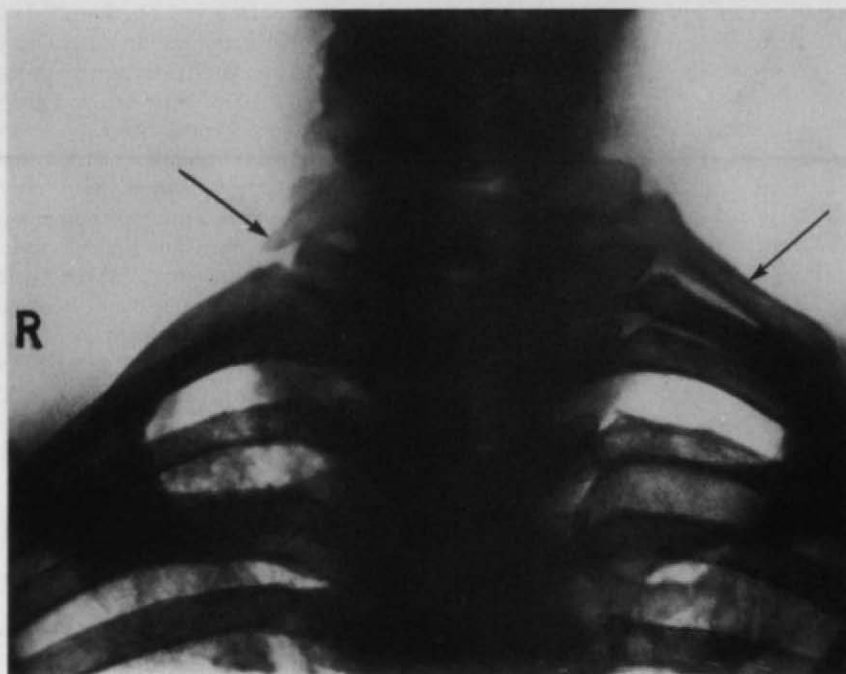


Fig. 6.67 Radiograph of a left cervical rib. On the right the anterior tubercle of C7 vertebra is greatly enlarged; a fibrous band passed from this tubercle to the first rib.

vertebral bodies and discs occurs in a ventral and lateral direction (the spinal cord prevents a corresponding growth dorsally). Thus in the adult and especially in the lumbar region the nucleus pulposus lies nearest to the *back* of the disc (Fig. 6.68) and if it herniates through the annulus it will be most likely to do so posteriorly and press on the roots of a spinal nerve near the intervertebral foramen, or on the spinal cord itself (see below).

The nucleus pulposus accounts for 15% of the whole disc. It contains about 90% water at birth, and this diminishes to about 70% in old age. The water content keeps the nucleus under constant pressure since its mucoprotein (proteoglycan) component has the property of imbibing and retaining water. This 'imbibition pressure' tends to force the vertebrae apart; with a load on the vertebral column the vertical pressure becomes a lateral thrust on the annulus, so distributing the load. Imbibition of water by the nucleus accounts for the overnight increase in height of a young adult by 1 cm; when upright during the day, water is squeezed out. In old age there is little height change between night and morning; imbibition pressure becomes less and the nucleus more fibrous. In astronauts who have been relieved of gravity there may be a height increase of several centimetres.

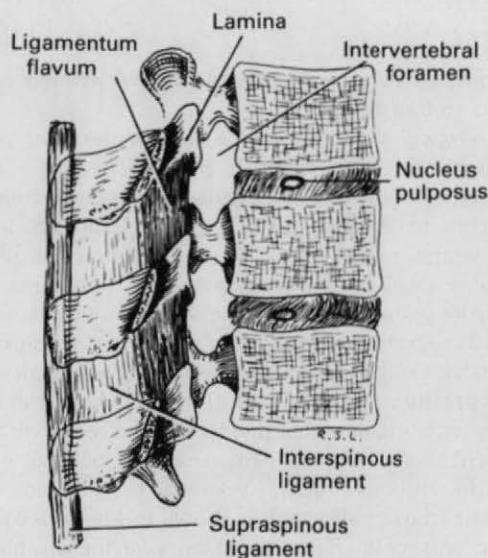


Fig. 6.68 Bisected vertebral column. The left half is seen from the right, so showing the inside of the vertebral canal, intervertebral discs in section, and the boundaries of two intervertebral foramina.

The relationship of *nerve roots* to intervertebral discs is of great importance, and is best understood by considering the lowest disc — the fifth lumbar or lumbosacral disc — which is the one most frequently herniated or prolapsed ('slipped disc'), with its nucleus pulposus being extruded posterolaterally. At the level of this fifth lumbar disc, the fifth lumbar nerve roots within their dural sheath have already emerged from the intervertebral foramen, hugging the *pedicle* of L5 vertebra and so not lying low enough to come in contact with the fifth lumbar disc. The roots that lie behind the posterolateral part of this disc are those of the first sacral nerve, and these are the ones liable to be irritated by a prolapse. Thus the general rule throughout the vertebral column is that when a disc herniates (usually posterolaterally rather than in the midline) it may irritate the nerve roots numbered *one below* the disc — S1 nerve by L5 disc, L5 nerve by L4 disc, C7 nerve by C6 disc; these are the commonest clinical examples.

The posterolateral lip or *uncus* on the upper surface of cervical vertebrae 3 to 7 (and also on T1 vertebra) may appear to form a joint with the adjacent disc because a small cavity may develop in this region (the so-called neurocentral, uncovertebral or *Luschka's joint*). These are not synovial joints though often stated to be so, but are due to degenerative changes in the disc.

The **anterior longitudinal ligament** extends from the anterior tubercle of the atlas to the front of the upper part of the sacrum. It is firmly united to the periosteum of the vertebral bodies, but is less so over the intervertebral discs. It is a flat band, broadening gradually as it passes downwards.

The **posterior longitudinal ligament** extends from the back of the body of the axis (second cervical) vertebra to the sacral canal. It narrows gradually as it passes downwards. It has serrated margins, being broadest over the discs to which it is *firmly* attached, and narrow over the vertebral bodies to which it is *more loosely* attached in order to give free exit to the basivertebral veins emerging from the backs of the bodies. At the top the ligament is continued above the body of the axis as the *tectorial membrane*.

Joints between the arches

The pedicles of adjacent vertebrae are not attached to one another, so leaving a space — the intervertebral foramen (see below) — for the emergence of the spinal nerve. All other parts of the neural arch are joined to their adjacent companions: the articular processes by synovial joints, and the remainder by ligaments, of which the most important are the ligamenta flava and the supraspinous ligament.

The joints between the articular facets of the superior articular processes of one vertebra and the inferior facets of the inferior articular processes of the vertebra above are properly called the *zygapophyseal joints*, but are more simply known as **facet joints**. They are synovial with a simple capsule which blends laterally with a ligamentum flavum. The articular surfaces allow gliding of one on the other; the direction of the surfaces determines the direction of the possible movements between adjacent vertebrae. The joints have a nerve supply from the nerve of their own segmental level and from the nerve of the segment above. *One nerve thus supplies two joints*; this may be important when considering nerve root pain which can be referred from facet joints. Although most of the weight transmission by the vertebral column takes place via the vertebral bodies and intervening discs, a small amount does occur through these joints. The lowest ones, between the inferior facets of L5 vertebra and the sacrum, are important in helping to prevent the vertebral column sliding off the sacrum; if the neural arch is fractured in front of these joints, the body of L5 slips downwards and forwards (*spondylolisthesis*).

The **ligamenta flava** are yellowish in colour from their high content of elastic fibres. They join the contiguous borders of adjacent laminae (Fig. 6.68). They are attached to the *front* of the upper lamina and to the *back* of the lower lamina — shallow grooves on the macerated vertebrae indicate their lines of attachment. They are stretched by flexion of the spine; in leaning forward their increasing elongation becomes an increasing antigravity support.

The **supraspinous ligaments** join the tips of adjacent spinous processes (Fig. 6.68). They are strong bands of white fibrous tissue and are lax in the extended spine. They are drawn taut by full flexion, and then support the spine (no action currents can be obtained from the erector spinae muscles when the spine is fully flexed, as in touching the toes). In the neck it is replaced by the ligamentum nuchae (p. 546).

The **interspinous ligaments** are relatively weak sheets of fibrous tissue uniting spinous processes along their adjacent borders (Fig. 6.68). They are well developed only in the lumbar region. They fuse with the supraspinous ligaments.

The **intertransverse ligaments** are similar weak sheets of fibrous tissue joining the transverse processes along their adjacent borders.

VERTEBRAL COLUMN

In the normal erect posture the vertebral column supports the head and trunk on the pelvis. (The pelvis

is supported by the lower limbs in standing and by its own ischial tuberosities in sitting.) This support is maintained by the bodies of the vertebrae and the intervertebral discs, which thus become progressively larger from above downwards. The curvatures of the spine are produced partly by the wedge-shape of the vertebral bodies, but mostly by the wedge-shape of the intervertebral discs. This is particularly noticeable in the lower part of the spine; L5 vertebra is usually wedge-shaped and the disc between it and the sacrum is very thick anteriorly (Fig. 5.51, p. 374).

Note that the upper surface of the sacrum slopes steeply downwards; sliding of L5 vertebra down this slope produces *spondylolisthesis*. This is normally prevented by the strength of the intervertebral disc and the direction of the articular facets between the neural arch of L5 and the first sacral arch (Fig. 6.82). Bony locking at this synovial joint prevents forward displacement of L5 vertebra if the neural arch is intact; in spondylolisthesis the pedicle of L5 is deficient.

The **vertebral canal** (p. 536) becomes progressively smaller from above downwards. It is closed anteriorly by the vertebral bodies, the intervertebral discs and the posterior longitudinal ligament and posteriorly by the laminae and the ligamenta flava. Laterally it is occupied by the pedicles, which are narrower than the height of the vertebral bodies. Thus a series of **intervertebral foramina** is produced *between adjacent pedicles* which form the *upper and lower* boundaries of each foramen. In the thoracic and lumbar regions each intervertebral foramen is bounded *in front* by the lower part of a body of a vertebra and the adjacent intervertebral disc, and *behind* by the facet joint and its capsule (Figs 6.77 and 6.78). In the cervical region the anterior boundary is slightly different because the pedicle arises from a little lower down the back of the body, so that a small part of the vertebral body below the disc is also included in this anterior boundary (Fig. 6.85). The intervertebral foramina lodge the spinal nerves and posterior root ganglia and give passage to the spinal arteries and veins.

MOVEMENTS OF THE VERTEBRAL COLUMN

In general the movements of the spine are simple enough. Flexion and extension, and lateral flexion (or abduction) are possible in cervical, thoracic and lumbar regions, though in varying degree in the three parts. Rotation occurs, strangely enough, mainly in the thoracic region. Movements of the head occur at the specialized atlanto-occipital and atlantoaxial joints and are considered on page 541. For the vertebral column as a whole the movements are best understood by consid-

ering each of the three regions separately. In each region movements occur around the nucleus pulposus as around a ball-bearing, and the direction of the movements is determined by the direction of the articular facets on the neural arches.

Lumbar region

Examine the five lumbar vertebrae in an articulated skeleton. The articular facets lie in an anteroposterior plane; they lock, and greatly limit rotation of the bodies on each other. Flexion and extension are free, and a good deal of abduction is possible; combination of these movements produces circumduction, but, to repeat, *practically no rotation is possible* except at the lumbosacral joints where a few degrees are possible.

Thoracic region

Examine the articulated thoracic vertebrae. The synovial joints between T12 and L1 are lumbar in type (Fig. 6.78); elsewhere the direction of the articular facets on the neural arches is quite different. On any one neural arch the upper facets face backwards and laterally (Fig. 6.66); they lie on the circumference of a circle whose centre lies in the vertebral body. The lower facets are reciprocal. Thus rotation of the bodies on each other is possible, in spite of the splinting effect of the ribs.

Flexion and extension occur, as well as abduction (lateral flexion). The thoracic spine is thus the most versatile region of all, though the *range* of movements is limited by the ribs. Flexion of the thoracic spine crowds the ribs together (expiratory), extension spreads the ribs (inspiratory), while abduction crowds them on the concave side and spreads them on the convex side. Abduction involves sliding of the neural arches downwards and backwards on the concave side and upwards and forwards on the convex side, thus producing passively a certain amount of simultaneous rotation. However, clinical studies suggest that the lower three or four thoracic vertebrae behave like lumbar vertebrae as far as rotation is concerned, with negligible movement; only above about T9 does it become significant. It is possible that this difference is correlated with the attachments and actions of the external oblique muscle: the lower part runs between the lower ribs and iliac crest of its own side, but the aponeurotic fibres of the upper part cross the midline to reach higher ribs of the opposite side, so exercising a spiral rotatory action on the middle and upper part of the thorax but not on the lower part.

Cervical region

The atlanto-occipital and atlantoaxial joints are specialized for head nodding and head rotation. They are considered below.

The articular facets of the other joints slope similarly to those in the thoracic region, but they do not lie on the circumference of a circle. Looking along them will confirm that they both lie in the same plane. While flexion and extension are free, *pure* rotation is obviously impossible. Abduction is not a simple movement. The neural arch of the abducted vertebra slides downwards (and therefore backwards) on the concave side and upwards (and therefore forwards) on the convex side, thus inevitably producing a concomitant rotation greater than that produced in abduction of the thoracic spine.

SPECIAL VERTEBRAE AND JOINTS

Atlas and axis

The first and second cervical vertebrae (atlas and axis) are atypical in several respects, both structural and functional. Weight-bearing between them and the skull is not by way of the vertebral bodies, and their joints permit a much wider range of movement than elsewhere in the vertebral column.

The **atlas** (Fig. 6.69) lacks a centrum. The vertebral arch has become modified to form a thick *lateral mass* on each side, joined at the front by a short *anterior arch* and with a longer *posterior arch* at the back. The *articular facets* on the upper and lower surfaces of the lateral mass differ markedly and are the clue to identifying which surface is which. The *upper* surface is *kidney-shaped* and concave for articulation with the occipital condyle, while the *lower* is *round* and flat for the lateral atlanto-axial joint. The articular facets are in line with the uncovertebral joints (p. 539) of the other cervical vertebrae, not with the articular facets on the neural arches. Thus the C1 and C2 nerves send their anterior rami behind, and not in front of, the joints. The anterior arch of the atlas represents morphologically the ossified hypochordal bow which is represented in the thorax by the intermediate strand of the radiate ligament of the head of the rib (p. 243).

The **axis** is characterized by the dens and a large spinous process (Fig. 6.70). The *dens* (*odontoid process*), long believed to be the centrum of the atlas, appears from comparative studies to be a development in its own right. It has an *articular facet* at the front for the joint with the anterior arch of the atlas. It bears no weight. The weight of the skull is transmitted through the lateral mass of the atlas to the *superior articular*

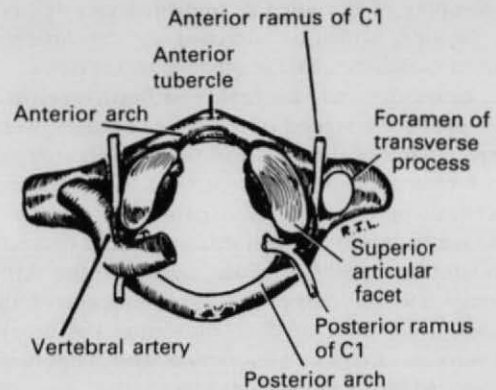


Fig. 6.69 Superior surface of the atlas. C1 nerve divides into anterior and posterior rami just behind the atlanto-occipital joint (right side), where it lies in the groove beneath the vertebral artery (left side).

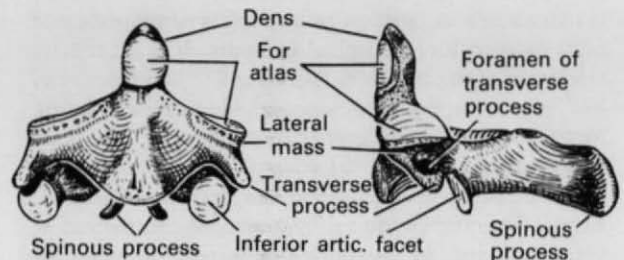


Fig. 6.70 Anterior and lateral views of the axis.

process of the axis which lies immediately lateral to the dens. The lower articulations of the axis are as for the ordinary cervical vertebrae — body to body with intervening disc and the two uncovertebral joints, and the ordinary articular facets on the neural arch. From the axis downwards the weight of the skull is supported by the vertebral bodies. The *bifid spinous process* is very large; this is due to powerful muscle attachments, the semispinalis cervicis from below and muscles of the suboccipital triangle above (Fig. 6.75).

The *atlanto-occipital* and the *atlantoaxial joints* are adapted to provide freedom of head movement, the former for nodding and lateral flexion, the latter for rotation.

The **atlanto-occipital joint** is a synovial joint between the convex occipital condyle and the concave facet on the lateral mass of the atlas. Both surfaces are covered with hyaline cartilage. The epiphyseal line between basiocciput and jugular process crosses the occipital condyle along the line of the hypoglossal canal, into which it extends (Fig. 8.9, p. 659). The

synovial cavity of the joint is contained in a lax but strong capsule, which is attached to the articular margins of both bones, and innervated by C1 nerve.

The **anterior and posterior atlanto-occipital membranes** are attached to the upper borders of the respective arches of the atlas and to the outer margins of the foramen magnum (Fig. 6.69). The anterior membrane completely closes the space between the two synovial joints, but the posterior membrane is deficient at each lateral extremity to allow passage for the vertebral artery and C1 nerve; the lateral margin of the membrane sometimes ossifies, converting the groove for the vertebral artery into a foramen. The membranes are innervated by C1 nerve (Fig. 6.96).

The curved surfaces of the joint are well adapted for head flexion and extension, and allow also for a considerable amount of abduction (lateral flexion) of the skull on the atlas. In the ordinary erect position the centre of gravity of the skull lies in front of the joint and the head is maintained in position by the tonus of the extensor muscles, notably semispinalis capitis. It is flexed by relaxation of the extensors (i.e. by gravity) and, actively, by longus capitis and sternocleidomastoids acting together. The effect of gravity is considerable (the head weighs over 3 kg or 7 lb) and, of course, varies with position, being greatest when the neck is horizontal. Lateral flexion is produced by unilateral contraction of such muscles as sternocleidomastoid, longissimus capitis, etc.

No rotation is possible at the atlanto-occipital joints. The articular surfaces are sections of a spheroid, like an egg lying on its side. Half buried in a reciprocal socket, the egg can be rolled to and fro in sagittal and coronal planes; but its oval shape prevents rotation around a vertical axis.

The **median atlantoaxial joint** is where the dens articulates with the back of the anterior arch of the atlas (Fig. 6.71). The smooth facets seen on the dry bones are covered with hyaline cartilage in life, with a capsule attached to their margins to make this a small synovial joint. The dens is held in position by the transverse limb of the cruciform ligament (see below); between the two is a relatively large bursa.

On each side there is a **lateral atlantoaxial joint** (also synovial) between the inferior articular facet of the atlas and the superior articular facet of the axis (Fig. 6.71). The joint surfaces are circular and flat with hyaline cartilage, and there is a lax capsule supplied by C2 nerve.

In addition to the joints, certain accessory ligaments connect the axis to the occiput, bypassing the atlas: the tectorial membrane, cruciform ligament, apical ligament and the paired alar ligaments.

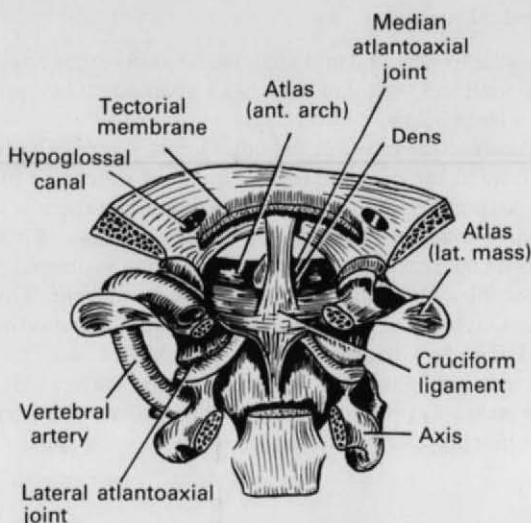


Fig. 6.71 Cruciform ligament from behind, exposed by removal of most of the tectorial membrane.

The **tectorial membrane** (not to be confused with the structure of the same name in the cochlea of the ear) extends upwards in continuity with the posterior longitudinal ligament. It is attached to the back of the body of the axis and diverges upwards to become attached to the margin of the anterior half of the foramen magnum. It lies in front of the spinal dura mater, which is firmly attached to it. This attached part of the dura mater, and *no other part*, serves also as a ligament across the atlantal joints (Fig. 6.72).

The **cruciform ligament** lies in contact with the front of the tectorial membrane. It consists of a strong *transverse band* attached to the atlas and a *longitudinal band* which joins the body of the axis to the foramen magnum (Fig. 6.71). It holds the dens in position; rupture of this ligament allows the dens to dislocate backwards with fatal pressure on the medulla. It articulates with the back of the dens by a large synovial bursa which is surrounded by a loose fibrous capsule.

The weak **apical ligament** lies in front of the upper longitudinal band of the cruciform ligament. It joins the apex of the dens to the anterior margin of the foramen magnum, and is a fibrous remnant of the notochord.

The **alar ligaments** lie obliquely one on either side of the apical ligament. Attached to the sloping upper margin of the dens they diverge upwards to be attached to the margins of the foramen magnum. They limit rotation of the head and are very strong.

Immediately in front of the alar and apical ligaments lies the anterior atlanto-occipital membrane.

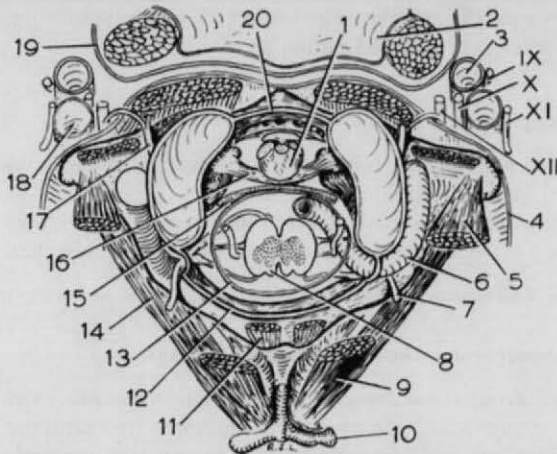


Fig. 6.72 Atlas and related structures. This complex diagram is clarified if the atlanto-occipital membranes and joint capsules are picked out in colour (say green) and the vessels and nerves tinted. The apparent chaos of such an assortment of structures becomes orderly if the regions are studied separately.

1. Dens of axis with apical and alar ligaments. 2. Mucosa of nasopharynx over levator palati. 3. Internal carotid artery and last four cranial nerves (Roman figures). 4. Prevertebral fascia. 5. Obliquus capitis superior. 6. Vertebral artery. 7. Posterior ramus of C1. 8. Medulla/spinal cord junction (denticulate ligament, accessory nerve and roots of C1 not labelled). 9. Rectus capitis posterior major. 10. Spinous process of axis. 11. Rectus capitis posterior minor, from posterior arch of atlas. 12. Posterior atlanto-occipital membrane. 13. Spinal dura and arachnoid. 14. Obliquus capitis inferior. 15. Tectorial membrane. 16. Transverse band of cruciform ligament. 17. Anterior ramus of C1 giving branch to hypoglossal nerve and ending in longus capitis. 18. Internal jugular vein. 19. Pharyngobasilar fascia. 20. Anterior atlanto-occipital membrane.

Movements at the atlantoaxial joints are simply those of rotation about a vertical axis passing through the dens. The atlas rotates by its anterior arch and transverse limb of the cruciform ligament gliding around the dens and the lower flat facets on its lateral mass gliding on the superior facets of the axis. The head rotates with the atlas; the curved surfaces of the atlanto-occipital joints do not allow independent rotation of occiput on atlas.

The muscles chiefly responsible for rotation are sternocleidomastoid, splenius capitis and the inferior oblique, usually with other muscles acting in synergism to prevent lateral flexion.

SUMMARY OF MOVEMENTS IN THE VERTEBRAL COLUMN

From the fixed sacrum up to the mobile skull a survey

of the whole column can now be made. Flexion and extension are common to all parts. These movements are very free in the specialized atlanto-occipital joint and in the lumbar region, free in the cervical region, and restricted in the thoracic region. Lateral flexion (or abduction) is free in the lumbar region and the atlanto-occipital joints, less free in the neck and rather restricted in the thorax. Rotation is free in the specialized atlantoaxial joints. In the remainder of the vertebral column rotation is negligible except in the thoracic region. Rotation is almost absent in the lumbar region.

Blood supply of the vertebral column

The vertebrae and the longitudinal muscles attached to them are supplied by segmental arteries. The ascending cervical, the intercostal and the lumbar arteries give multiple small branches to the vertebral bodies. The extensor muscles are supplied in the neck by the occipital, the deep cervical and the transverse cervical arteries. In thoracic and lumbar regions the muscles receive posterior branches of the intercostal, lumbar and lateral sacral arteries.

Venous drainage. The richly supplied red marrow of the vertebral body drains almost wholly by a pair of large *basivertebral veins* into the **internal vertebral venous plexus** (p. 397). Drainage of the neural arch and of the attached muscles is into the *external vertebral venous plexus*. This plexus is intramuscular, and non-existent over the bare fronts of the vertebral bodies. The internal and external plexuses together drain into the regional segmental veins (vertebral, posterior intercostal, lumbar and lateral sacral veins). In the pelvis venous communication is thus established with the pelvic viscera, in the abdomen with the left renal vein, in the thorax with the veins of the breast that enter the intercostal veins and in the neck with the inferior thyroid veins via the brachiocephalic veins. In this way, by reflux blood flow through these largely valveless veins, malignant disease possibly spreads from prostate, uterus, breast and thyroid gland to the bodies of the vertebrae.

MUSCLES OF THE VERTEBRAL COLUMN

The movements of the vertebral column are produced by muscles widely separated from each other and, in almost all cases, are assisted by gravity. The action of paradox, whereby muscles 'pay out rope' against gravity, must always be borne in mind. Nevertheless for the sake of simplicity it is desirable to discuss the actions of the various muscle groups contracting as prime movers, and only after these actions are under-

stood to interpret the functions of the muscles when combined with gravity.

At the front of the vertebral column are some **flexor muscles** derived from the innermost of the three layers of the body wall, constituting the prevertebral rectus. Longus capitis, longus colli and psoas belong to this group. They are supplied segmentally by *anterior rami*. The more usual muscles for flexing the spine are, however, the two rectus abdominis muscles, which act indirectly by way of the pelvis and thoracic cage. Rotators of the column are to be found in the abdominal flank muscles (the two obliques) which likewise act indirectly on the spine by way of the pelvis and the thoracic cage (p. 300).

Running along the whole length of the vertebral column from skull to sacrum is a posterior mass of mainly longitudinal **extensor muscles**, derived from the outer of the three layers of the body wall and supplied segmentally by *posterior rami*, being the only muscles in the body so supplied. They form a bulge on either side of the midline of the back, often best seen in the lumbar region. In the neck the muscle mass is specialized into certain separate muscles for particular head movements, and its superficial layer is the splenius muscle. Elsewhere it is covered by the thoracolumbar fascia. Description of the individual muscles involves mentioning a host of group names and subdivisions, but the student should not despair; although the general pattern and classification should be understood, the precise details of most of them are not required either for examinations or in clinical practice. Although not strictly correct, it is usually sufficient for both students and clinicians to group the whole lot together as *erector spinae*. The account that follows does break the groups down into their constituent parts, more to provide a reference list that illustrates the complexities rather than details that have to be remembered. It must be appreciated that the extent of the muscle fibres is not uniform; some are short and some are long, like a system of guy ropes. It is evident that the shortest fibres must lie deepest, and so it is that the deepest layer of all consists of muscles that extend no further than adjacent vertebrae.

The deepest muscles are the *interspinales* and *intertransversales*; they are small and unimportant. The remainder form intermediate and superficial masses collectively called transversospinalis and erector spinae, each of which is composed of three groups. *Transversospinalis* includes the *rotatores*, *multifidus* and *semispinalis*, while *erector spinae* comprises *iliocostalis*, *longissimus* and *spinalis*. The *iliocostalis* and *longissimus* parts of *erector spinae* can each be subdivided into lumbar, thoracic and cervical parts, while

semispinalis and the *spinalis* part of *erector spinae* has thoracic, cervical and capital parts.

Deep layer

The *interspinales* join adjacent borders of spinous processes, alongside the interspinous ligaments. The *intertransversales* join adjacent transverse processes; they are best developed in the upper part of the vertebral column.

Transversospinalis (intermediate layer)

As a group these muscles run from transverse processes to spines, hence the name. The *rotatores* are small, but *multifidus* and *semispinalis* form much larger muscle masses which, like the parts of *erector spinae*, are often made up of multiple musculotendinous bundles.

The *rotatores* are interesting in that they are confined to the thoracic spine, the only region where pure rotation occurs. Each extends from the base of a transverse process to the root of the spinous process of the vertebra above (Fig. 6.73); due to the declination of the spinous processes the course of the fibres is horizontal, giving them the best possible leverage. In the suboccipital triangle these muscles are specialized into the *recti* and *obliques* (p. 546).

Multifidus fibres slope upwards from the laminae, mamillary processes or transverse processes to the spinous processes of vertebrae two or three above their level of origin. They commence at the upper part of the sacrum and extend to the upper part of the neck (C2).

Semispinalis lies on the surface of *multifidus*. Its fibres arise from the transverse processes and slope steeply upwards to the spinous processes. It extends from the lower thoracic region to the skull. **Semispinalis thoracis** extends from the transverse processes of the lower thoracic vertebrae and each part is inserted into the spinous process six or more vertebrae higher. **Semispinalis cervicis** arises in continuity at a high level; the uppermost part of the muscle is inserted into the concavity of the bifid spinous process of the axis.

Semispinalis capitis is the most powerful part of this layer. It arises from the transverse processes of the upper six thoracic and lower four cervical vertebrae and is inserted into the occipital bone near the midline, between the superior and inferior nuchal lines. Its medial part is usually somewhat separated from the main mass; a tendinous intersection usually present denotes the segmental origin of the muscle. It covers the *semispinalis cervicis* and lies beneath *splenius* and

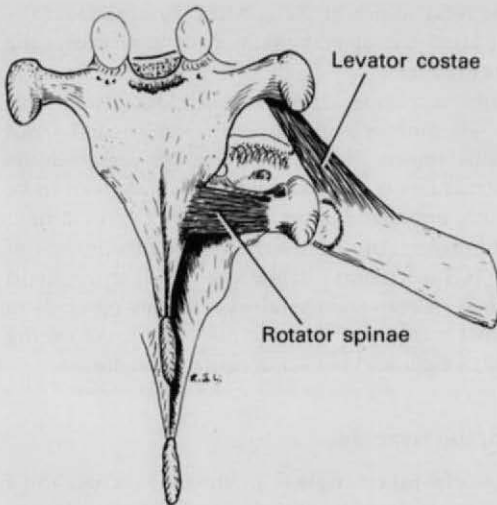


Fig. 6.73 Rotator spinae and levator costae muscles.

trapezius. It can be seen in contraction in a thin neck, for the overlying muscles are but flat sheets. It is the chief extensor of the head, and in the erect position or in leaning forward it is in isometric contraction as a muscle of posture. Like the soleus muscle in the calf it contains a large plexus of veins within as well as around it.

The ascending branch of the superficial cervical artery passes up behind the muscle, and the deep cervical artery (the ascending branch of the costocervical trunk) passes up in front of it. Each anastomoses with a branch of the occipital artery. It is their corresponding veins that form the plexus already mentioned.

Erector spinae (superficial layer)

This forms the most powerful muscle group. It commences below, deep to the lumbar fascia, on the back of the sacrum and the inner side of the iliac crest. The thick mass of fibres diverges upwards and divides into two main bundles, iliocostalis laterally and longissimus medially (Fig. 6.74). The **iliocostalis** fibres are inserted by shining tendons into the angles of the lower six ribs. From these attachments new muscle bundles arise and each runs up to be attached to the angle of the sixth rib above. From there further fibres run up to reach the transverse processes of the lower four cervical vertebrae. It should be noted that this mass, which could be called costocervicalis, forms the most lateral part of erector spinae. Fibres from below are attached into ribs as far lateral as possible, beneath the thora-

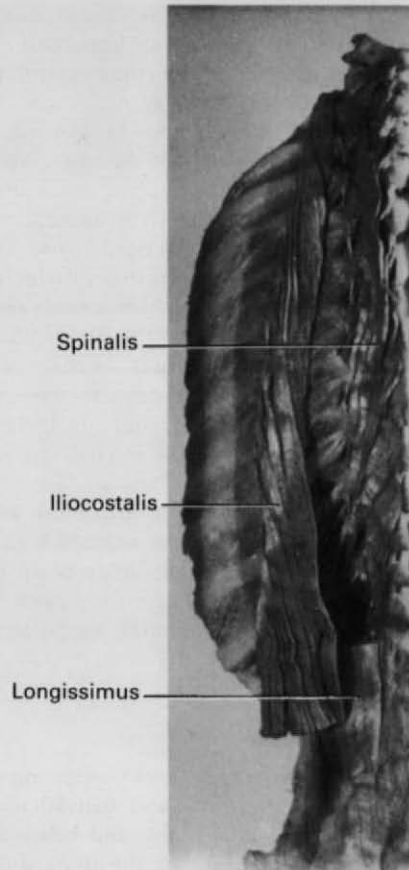


Fig. 6.74 Parts of the left erector spinae muscle. The most lateral mass is iliocostalis. Most of longissimus (whose lower part is seen adjacent to iliocostalis) has been removed to show various parts of spinalis.

columbar fascia, just within the angle of each rib. These fibres are replaced at their insertions by new fibres which arise by tendons on their medial side to pass upwards.

The more medial longissimus bundle arising from the sacrum and iliac crest passes up to be inserted into the gutter between transverse processes and ribs; this is **longissimus thoracis**. At its insertion it is replaced by new fibres on the medial side that pass up to the transverse processes of the lower cervical vertebrae; this is **longissimus cervicis**. From these insertions new bundles arise and pass upwards as **longissimus capitis**; this muscle is inserted into the mastoid process deep to splenius capitis. It overlies the lateral border of semispinalis capitis and is covered over by splenius.

The most medial part of erector spinae is the **spinalis** part. Its fibres run alongside the spinous

processes and are small and often indefinite, usually blending with semispinalis. It is not an important part of erector spinae, but it should not be confused with the interspinales muscles of the deepest layer.

Thus the whole mass of back muscles consists of large numbers of muscle and tendon bundles. Much back pain is presumably due to stretching and tearing between muscle, tendon and bone, for anatomically there are multiple sites where this can occur.

In the neck, the underlying extensor muscles are bound down by **splenius**, a flat sheet arising from upper thoracic spinous processes and the supraspinous ligament, and from the ligamentum nuchae. The fibres slope upwards and laterally, deep to trapezius and sternocleidomastoid (Fig. 6.2), and are inserted (as *splenius capitis*) into the superior nuchal line and mastoid process, and (as *splenius cervicis*) into the transverse processes of the upper three or four cervical vertebrae (deep to levator scapulae). The whole muscle is like a bandage that holds down the deeper extensor muscles at the back of the neck. It, like the muscles deep to it, is supplied by posterior rami.

BACK OF THE NECK

The back of the neck consists of muscles connecting the skull to the spine and pectoral girdle and, beneath these muscles, of two parts which lie above and below the prominent spine of C2 vertebra. In the midline the ligamentum nuchae separates the two sides and the flat sheet of oblique muscle fibres named splenius separates the deep extensor mass (supplied by posterior rami) from the superficial muscles supplied by the accessory nerve—trapezius and sternocleidomastoid. These are attached edge to edge along the superior nuchal line of the occipital bone. From this attachment they diverge to the pectoral girdle, enclosing within their borders the apex of the posterior triangle of the neck. Above the superior nuchal line lies the scalp, while below this level the fleshy mass of the neck is seen; the junction of the two marks the attachment of the tentorium cerebelli and the line of the transverse sinus within the cranium. The muscles of the back of the neck cover the posterior cranial fossa and the cerebellum; above their attachment is the supratentorial compartment containing the occipital lobes of the cerebral hemispheres.

The **ligamentum nuchae** is a strong band of fibro-elastic tissue well developed in those mammals with protuberant necks and heads. In man, with his vertical neck, it consists of no more than a midline intermuscular septum of fibrous tissue. Triangular in shape, its three borders are attached to the external occipital

crest, the bifid spines of the cervical vertebrae and the investing layer of deep cervical fascia which encloses the trapezius muscles.

Beneath trapezius and sternocleidomastoid lies splenius. Beneath splenius lie semispinalis capitis and longissimus capitis. When all these are removed the deeper structures of the back of the neck are seen to be divided into upper and lower portions by the prominent backward projection of the massive spinous process of the axis (C2 vertebra). Below this level semispinalis cervicis is seen converging almost vertically upwards to the internal surfaces of the bifid axial spine. Above the spine lie the right and left suboccipital triangles.

Suboccipital triangle

The **suboccipital triangle** is bounded by rectus capitis posterior major and the superior and inferior oblique muscles (Fig. 6.75). Its floor contains the posterior arch of the atlas and the posterior atlanto-occipital membrane. Across the floor runs the vertebral artery, and through the floor emerges the suboccipital (C1) nerve. Across the roof run the greater occipital (C2) nerve and the occipital artery.

Rectus capitis posterior major is badly named; it is not vertical, but oblique. It arises from the outer surface of the bifid spinous process of C2 vertebra and extends obliquely upwards and outwards to be attached to the lateral part of the area below the inferior nuchal line. Its action is to extend the head and rotate it (with the atlas) back towards its own side.

The **inferior oblique (obliquus capitis inferior)** is attached between the outer surface of the bifid spine of the axis (below rectus capitis posterior major) and the back of the lateral mass of the atlas. Its action is to rotate the atlas (and the skull with it) back towards its own side.

The **superior oblique (obliquus capitis superior)** extends from the back of the lateral mass of the atlas to the lateral part of the occipital bone between superior and inferior nuchal lines. Attached to atlas and skull it can only move one on the other—the movement is of lateral flexion of the skull combined with slight extension.

Rectus capitis posterior minor is the only muscle attached to the posterior arch of the atlas. It arises from a small fossa near the midline and passes vertically upwards to be inserted into the medial part of the area below the inferior nuchal line. Its action is to extend the head.

Nerve supplies. All four muscles are supplied by the posterior ramus of C1.

Actions. The actions of the small muscles as stated,

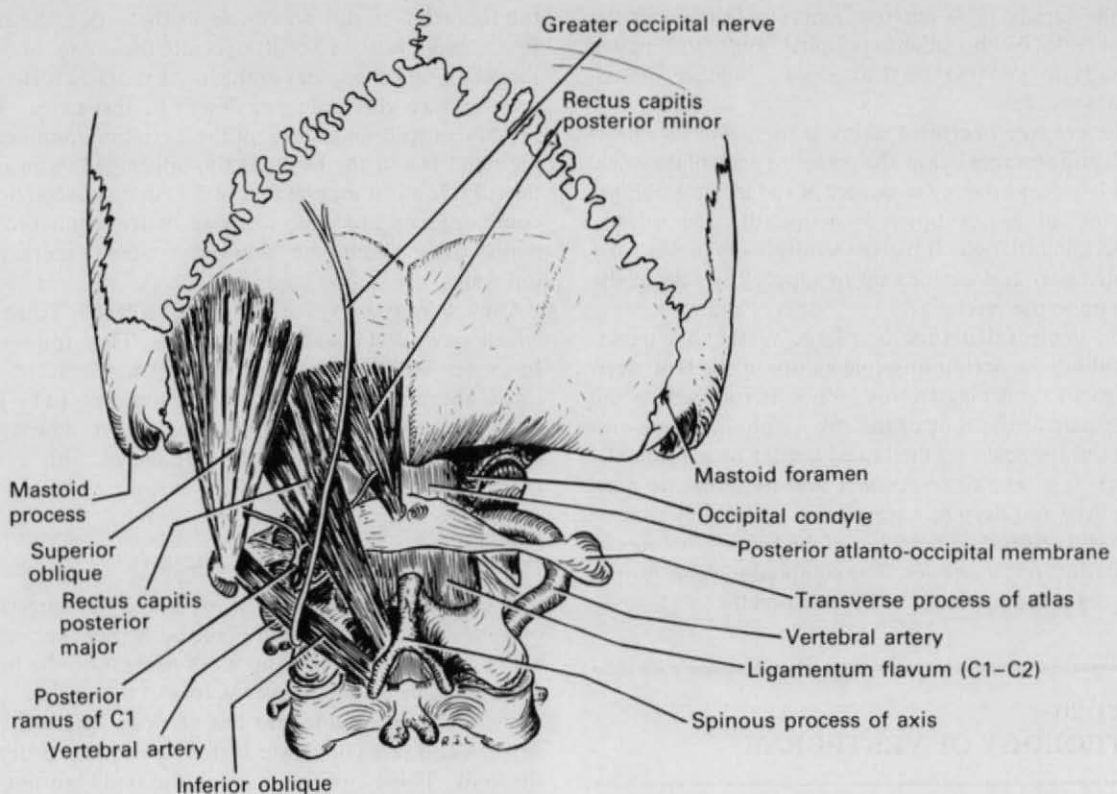


Fig. 6.75 Suboccipital region and the suboccipital triangle.

and those of the rectus capitis anterior and lateralis (p. 440) are of use less as prime movers than as synergists. They adjust and stabilize the skull by cancelling out any unwanted secondary effects of such powerful prime movers as sternocleidomastoid, splenius, semispinalis, longissimus, etc. They have an unusually high proportion of muscle spindles, and the size of their motor units is small (like the extraocular muscles) with only five or so muscle fibres for each nerve fibre.

The second part of the **vertebral artery** ascends through the foramina in the transverse processes of the upper six cervical vertebrae, anterior to the emerging spinal nerves. It gives a *spinal branch* into each intervertebral foramen. Its course from C6 to C2 vertebra is vertical. Between the foramina in the transverse processes of the axis and atlas it passes laterally, and here has a pronounced posterior convexity. This must be to allow for taking up slack during rotation of the atlas on the axis (Fig. 6.96).

On emerging from the foramen in the transverse process of the atlas, the vertebral artery passes medially behind the atlanto-occipital joint. Here it lies in the

floor of the suboccipital triangle before piercing the lateral angle of the posterior atlanto-occipital membrane. It deeply grooves the posterior arch of the atlas before entering the skull through the foramen magnum.

The **vertebral veins** exist only in the neck, not inside the skull which the vertebral arteries enter. Some of the blood from the muscles of the suboccipital triangle is collected in a plexus of veins that descends alongside the vertebral artery, within and without the foramina in the transverse processes. From this plexus two vertebral veins usually emerge, one from the sixth with the vertebral artery and one alone through the foramen in the transverse process of C7 vertebra. The vertebral plexus of veins receives the segmental drainage of the cervical part of the spinal cord along the nerve roots, as well as drainage from the internal vertebral plexus (p. 543). The two vertebral veins join the brachiocephalic vein in the root of the neck, on the apex of the lung (Fig. 6.7B).

In the groove between artery and bone on the posterior arch of the atlas lies the **suboccipital (C1) nerve**. Its posterior ramus passes backwards to supply the two recti, the two obliques and the upper fibres of semi-

spinalis capitis. The anterior ramus winds round the lateral side of the atlanto-occipital joint and passes forwards to join the cervical plexus. Neither branch reaches the skin.

The **greater occipital nerve** is the posterior ramus of C2 and emerges below the posterior arch of the atlas. It curls around the lower border of the inferior oblique muscle and passes upwards across the roof of the suboccipital triangle. It pierces semispinalis capitis (first supplying it) and extends up to supply the skin of the scalp up to the vertex.

The **occipital artery** is a large vessel that passes back along the occipitomastoid suture of the skull deep to digastric and longissimus capitis. It runs across the upper part of the roof of the suboccipital triangle and passes to the scalp on the lateral border of semispinalis capitis. It gives off descending branches that lie both superficial and deep to semispinalis, where they anastomose with ascending branches of the transverse cervical and costocervical arteries. The companion veins form a rich plexus around and within semispinalis.

PART 20

OSTEOLOGY OF VERTEBRAE

A simple review of the principal features of vertebrae is given on page 536, with enough detail to understand how vertebrae articulate into a column that works. The following accounts are intended *only* for those who must have more complete details of the individual bones.

THORACIC VERTEBRAE

It is better to begin with these, since the costal elements ossify separately as thoracic ribs. *Examine the articulated column*, allowing for possible distortion introduced by artificial discs. Note the backward convexity of the normal kyphosis; this results in the upper thoracic vertebrae leaning forwards, so their transverse processes are tilted up a little. This tilts the corresponding rib necks. The neck of the first rib, for example, slopes upwards from the head to the tubercle (Fig. 4.5, p. 247). The concave facets on these upper transverse processes thus look somewhat downwards, while the flat facets on the lower transverse processes look somewhat upwards.

The spinous processes slope downwards with gradually increasing declivity as far as T7, below which they very gradually level out to become almost horizontal at T12. Thus the tips of the upper four spines lie opposite

the tubercles of ribs one lower in the series, the next four spines (those of T5–8) opposite those two lower in the series, and the spines of the lower thoracic vertebrae are opposite ribs only one lower in the series. The prominent spinous process of the 'vertebra prominens', seen and felt in the living at the upper end, is usually that of C7, but it may be that of T1, so it is uncertain to count spinous processes downwards from this prominence (they should be counted up from the L4–5 interval).

Only a narrow space separates adjacent laminae, which are wide and imbricated. The transverse processes are all of corresponding length except the much shorter ones of T12 and sometimes T11. The bodies become more massive from above down; the middle four often show slight asymmetry, with a left-sided excavation produced by the aorta.

A typical thoracic vertebra (Fig. 6.76)

The essential characteristic is, of course, the presence of *costal facets*. On each side of the body these consist of a pair of demifacets. The upper of these is on the body at its junction with the upper border of the pedicle. It is semicircular in outline and lies vertical. The lower is smaller, and faces downwards from the lower border of the body. These two facets lie on the body but not on the centrum (in morphological language they are on the neural arch—p. 536). Covered with hyaline cartilage, each makes a separate synovial joint with one of the facets of a rib head (p. 243).

The *body* is concave from above down around its circumference, and the surface is perforated by multiple vessels. The anterior convexity gives attachment to the anterior longitudinal ligament. From T4 downwards the body shows a sharper curve around this anterior convexity, giving the upper and lower surfaces a heart-shaped outline. This outline is asymmetrical from a slight left-sided excavation produced by the descending aorta. The posterior surface of the body is concave from side to side, making with the laminae a *vertebral foramen* that is almost *circular* in outline (in lumbar and cervical vertebrae the foramen is more triangular). Two large foramina separated by a strip of bone (looking like a small pair of nostrils) open centrally on the back of the body; they are for the basivertebral veins. They are spanned by the narrow part of the posterior longitudinal ligament, which is only loosely attached at the upper and lower borders of the body (but firmly to the adjacent discs). The upper and lower surfaces of the body are similar. Each surface is enclosed in a heart-shaped ring of compact bone at the margin. This is the fused epiphyseal ring of the body, and it encloses a large

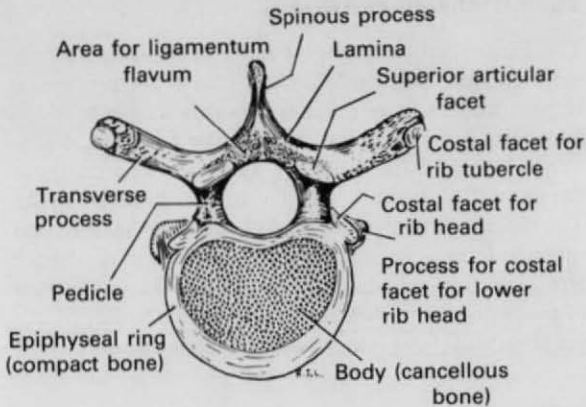


Fig. 6.76 Typical thoracic vertebra from above.

central area in which cancellous bone reaches the surface. Both compact and cancellous areas are covered in life by a thin plate of hyaline cartilage, to which the fibres of the annulus fibrosus are attached (p. 537).

The *pedicle* projects back from the upper half of the body. Its upper border is level with the upper surface of the body. Thus the body itself takes no part in the formation of the intervertebral foramen above it (Figs 6.77 and 6.78). The upper border of the pedicle curves up in a slight concavity (the *superior vertebral notch*) to a *superior articular process*. The lower border curves down to the *inferior articular process*, so making the deeply concave *inferior vertebral notch* which forms the upper boundary of the intervertebral foramen. This accommodates the thoracic nerve of the same number as the vertebra.

The flat *laminae* slope down from the pedicles to unite in the midline and complete the neural arch. Their upper borders slope down to form a deep notch. Between the superior articular processes this notch is grooved from side to side, along the *posterior* surface of the lamina, for attachment of the ligamentum flavum which goes up to the vertebra above. The lower border of the lamina is likewise deeply grooved between the inferior articular processes, but this groove lies along the *anterior* surface of the lamina. It is for attachment of the ligamentum flavum coming up from the lamina below. Thus alternate laminae and ligamenta flava are imbricated, like overlapping tiles of a roof (Fig. 6.68).

The *superior articular process* projects up from the junction of pedicle and lamina. It carries an *oval articular facet*, set very steeply, facing *backwards* and slightly *laterally*; so the two articular surfaces lie on the arc of a circle, permitting rotation of adjacent bodies. The *inferior articular facets* are reciprocal, facing *forward* and

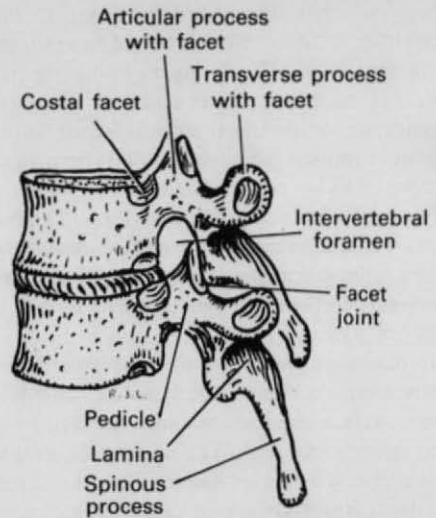


Fig. 6.77 Two articulated midthoracic vertebrae from the left. The intervertebral foramen is bounded in front by half of the body of the upper vertebra and the intervertebral disc, at the back by the facet joint, and above and below by pedicles.

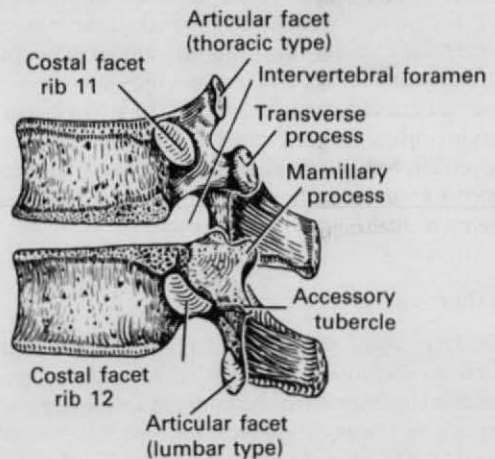


Fig. 6.78 T11 and T12 vertebrae from the left.

somewhat *medially*. They project below the pedicle at the inferior angle of the lamina. Upper and lower facets, each cartilage-covered, form synovial joints, with capsule and synovial membrane attached to the articular margins. The ligamentum flavum extends from one capsule across to the other and fills the bony hiatus between adjacent laminae. The main exit from the vertebral canal is the line of intervertebral foramina. Some small midline veins may run out between a pair of ligamenta flava to unite the internal and external vertebral venous plexuses.

The *spinous process* slopes down from the junction of the laminae. It tapers from a broad base down to a tip that is expanded. Weak interspinous ligaments and interspinous muscles connect adjacent sharp borders of the processes, while the thick and strong supraspinous ligament connects their expanded tips. The thoracolumbar fascia is attached here, with trapezius overlying splenius and latissimus dorsi. The base of the spinous process receives the rotator muscle from the vertebra below, and more superficially the multifidus, semispinalis and spinalis muscles are inserted into each side as far as the tip.

The *transverse process* projects backwards as well as laterally from the junction of pedicle and lamina. Its anterior surface expands towards the tip, to carry the characteristic *costal facet*. The upper six costal facets are concave, the lower ones flat (the hyaline cartilage that coats them is not always of uniform thickness, so the facet on the dried bone may not correspond accurately with the living cartilaginous facet). The tip of the transverse process gives attachment to the lateral costotransverse ligament. The root of the transverse process, adjoining the lamina, gives origin to a rotator muscle. Upper and lower borders carry weak intertransverse ligaments and muscles; the lower margin gives origin to a levator costae muscle, and receives the superior costotransverse ligament from the neck of the rib below. The posterior surface carries erector spinae attachments (semispinalis, longissimus) and the anterior surface is covered by the attachment of the costotransverse ligament (p. 243).

First thoracic vertebra

The body is broad, not heart-shaped. Longus colli is attached to its anterior convexity over the anterior longitudinal ligament. On the body, at its junction with the pedicle, is a large round facet for the single articular surface of the head of the first rib. There is a demifacet for the second rib at the lower border of the body. The pedicle is attached below the upper margin of the body, as in a cervical vertebra, so the body takes part in the formation of the intervertebral foramen above it as well as below it. These are the foramina for the exit of C8 and T1 spinal nerves.

Eleventh thoracic vertebra

This carries a *single costal facet*, behind the body on the upper part of the broad pedicle (Fig. 6.78). The articular facets are typically thoracic. The transverse process is often stunted. At times these features are shown also by T10 vertebra.

Twelfth thoracic vertebra

The broad pedicle carries a *single costal facet* near its lower margin (Fig. 6.78). The transverse process is stunted and its base projects upwards into a rounded mamillary process behind the articular facet and downwards into a sharp accessory tubercle. The posterior ramus of T11 nerve lies in the groove between them. The superior articular facet looks backwards like a typical thoracic facet. The inferior articular facet is lumbar in type, a vertical cylinder facing laterally. The upper limit of psoas major attachment is at the lower border of this vertebra, and psoas minor arises just above this.

LUMBAR VERTEBRAE

The normal lordosis of the lumbar vertebrae and the angulation between L5 and the sacrum (Fig. 5.51, p. 374) are best appreciated by examination of a fresh specimen; artificial discs used in the articulated skeleton are seldom thick and wedged enough. The *bodies* may be wedge-shaped, deep in front and shallow behind; this is especially so of the fifth. But as often as not they show no wedging, and if the five dry bones are piled on each other their spinous processes make a backward convexity. When separated by discs of normal thickness the bodies fan out enough to produce a backward concavity of the spine. The wedge-shaped discs themselves, not the bodies, produce the normal lordosis. The massive bodies increase in breadth from above down, and this is reflected posteriorly by a progressive widening between the articular processes. Thus in L1 and 2 the four processes make a rectangle set vertically; in L3 they may also make a vertical rectangle, or they may be like those of L4 and make a square; in L5 they make a horizontal rectangle. The *transverse processes* are variable in length, but the fourth is usually the longest. In the upper four they are spatulate and set well back on the pedicle (Fig. 6.66). The transverse process of the fifth, however, is quite characteristic. Short, massive, pyramidal, its base is attached from the pedicle *well forwards on the lateral side of the body itself* (Fig. 6.80). It is the only vertebra in which the transverse process joins the body (instead of the junction between pedicle and lamina) and this one feature makes L5 instantly recognizable.

From this general survey of the lumbar spine, study the individual characteristics of a single lumbar vertebra (Fig. 6.79). The *body* shares with the smaller thoracic vertebrae the characteristics of being concave from above down, of having pedicles attached to its *upper* half, and of being perforated by a pair of basivertebral veins posteriorly. It differs from the thoracic vertebra in being

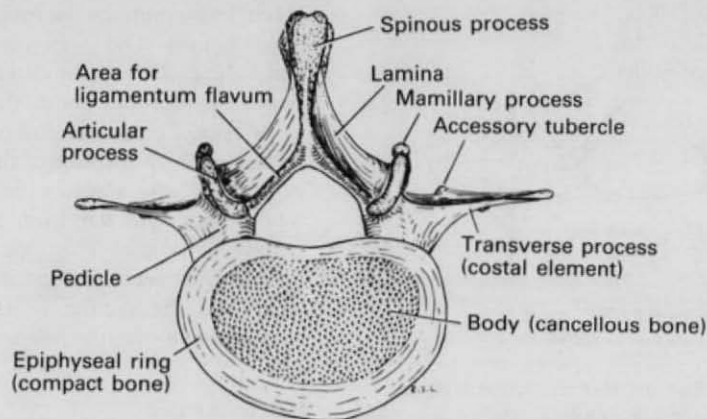


Fig. 6.79 Typical lumbar vertebra from above.

kidney- not heart-shaped, and the posterior surface is flatter, less concave from side to side, so the vertebral canal is not circular but somewhat *triangular* in cross-section. Anterior and posterior longitudinal ligaments are attached as in the thoracic vertebrae. Psoas major is attached to the upper and lower borders, but not to the concavity of the body, where psoas spans the vertebra on a fibrous arch. Lumbar vessels and sympathetic rami curve around beneath the fibrous arch.

The *pedicles* enclose intervertebral foramina identical in formation with the thoracic foramina. The *laminae* do not show such a downward slope as in the thoracic vertebrae, but the upper border is grooved posteriorly and the lower border is grooved anteriorly in identical manner, for attachment of the imbricated ligamenta flava.

The *spinous process* is roughly horizontal. The upper border is straight but the lower border curves down, producing the so-called hatchet shape. The interspinous ligaments are attached to adjacent upper and lower borders. The posterior border is much thickened for the supraspinous ligament. Interspinales and multifidus muscles are attached to the spines.

The *transverse processes* have already been noticed. The upper four, spatulate, are characterized by a vertical ridge on the anterior surface (palpable if not readily visible). This is for attachment of the psoas fascia and the anterior layer of the lumbar fascia. The medial and lateral arcuate ligaments are attached to the ridge on L1 transverse process. Medial to the ridge psoas is attached, while lateral to the ridge quadratus lumborum receives partial insertion. The tip of the transverse process receives the middle layer of the lumbar fascia (Fig. 1.10, p. 19). Adjacent borders carry

intertransverse ligaments and muscles. The posterior surface receives the attachments of erector spinae.

The *articular processes* are characteristic. The upper pair rise up and carry *articular facets* that face *medially* (the upper facets of L4 and 5 face posteriorly as well as medially). The articular surfaces are *cylindrical*, being concave from front to back (Fig. 6.79). The lower pair of articular processes project down from the lateral angles of the laminae and are mortised into the superior processes of the vertebra below. Each carries a reciprocal convex facet, a section of a vertical cylinder. It has already been explained that the transverse processes are fused ribs (costal elements), and now the true transverse element of the lumbar vertebra can be seen. It consists of two elevations with a groove between them made by the medial branch of the posterior ramus of the overlying lumbar nerve (Fig. 6.81). The *mamillary process* is a 'breast-shaped' convexity projecting back from the superior articular process behind the margin of the articular facet. The *accessory tubercle* lies below this, at the root of the transverse process; it varies from a prominent sharp spike to complete absence. The mamillary process and accessory tubercle together represent the stunted transverse process of a thoracic vertebra, and they carry similar attachments for back muscles (multifidus, longissimus). (Note the same arrangement in T12 vertebra in Fig. 6.78.)

Fifth lumbar vertebra

The characteristic *pyramidal transverse process* has been noted above (see Fig. 6.80). It carries the strong iliolumbar ligament, and quadratus lumborum arises

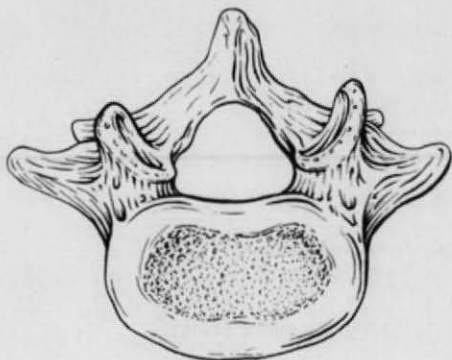


Fig. 6.80 L5 vertebra from above. Compare with Figure 6.79 and note that the transverse process extends well forward on to the side of the body — a feature unique to L5.

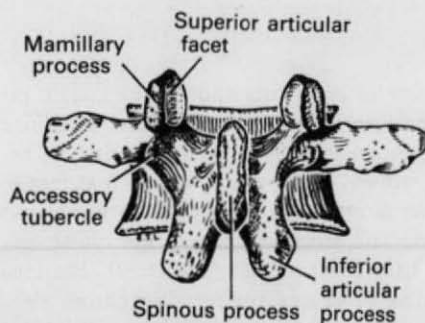


Fig. 6.81 L3 vertebra from behind.

from both. The anterior and middle layers of the lumbar fascia are attached to the process and the ligament. The inferior articular processes face well forwards, and are received into backward-facing facets on the sacrum, and this locking prevents L5 vertebra from sliding forwards down the slope of S1 vertebra. Furthermore, the adjacent bodies are strongly united by the intervertebral disc. Thus, although the sloping lumbosacral joint carries the whole body weight, it is extremely stable. A strongly contracting erector spinae acts as a supporting strap posteriorly.

The fifth lumbar vertebra may be fused on one or both sides to the first sacral vertebra, a condition known as 'sacralization'.

SACRUM

Five progressively smaller sacral vertebrae and their costal elements fuse to make this bone, which is triangular in outline and curved to a concavity towards the pelvis. It carries the whole body weight. It articulates with the ilium to make the upper posterior wall of the

pelvic basin but the sacroiliac joint so formed is *not weight bearing*. The sacrum is slung on ligaments above and behind the joint, and they carry the body weight. Below the sacroiliac joints the sacrum tapers off down to its apex. The anatomical position of the sacrum can be assessed by inspecting the articular facets for L5 vertebra. These surfaces are cylindrical, curved from side to side but flat from above down; *the concave cylinder lies vertical*. The upper surface of the first sacral body is thus seen to slope down at 30° or more, and from here the sacrum is directed backwards before curving down over the pelvic cavity.

Pelvic surface

This concave surface is smooth. In the midline five diminishing bodies are fused, with four ridges persisting to mark the lines of ossification; these transverse lines represent the intervertebral discs. On each side the four *anterior sacral foramina* are large but diminish from above down. The rounded bars of bone between adjacent foramina (costal elements) represent the heads and necks of ribs. The medial boundaries of the anterior sacral foramina are thus formed by the bodies of the sacral vertebrae, but the other three-fourths of their circumference is costal in origin. The rounded bar of bone above the first sacral foramen continues the arcuate line of the ilium to form the posterior part of the pelvic brim. This continues medially to the *sacral promontory*, the prominent anterior lip of the first sacral body.

The mass of bone lateral to the foramina, the *lateral mass*, is formed by fusion of the costal elements (shafts of ribs) with each other. It is deeply indented by grooves for the anterior rami of the upper four sacral nerves, which pass laterally from the anterior sacral foramina. Piriformis arises from the three ridges (costal elements) that separate the anterior foramina, and from the lateral mass nearby. Below the promontory peritoneum is draped over the upper two bodies, but the retroperitoneal rectum lies against the lower three bodies. The fascia of Waldeyer and the superior rectal vessels lie between the sacrum behind and the peritoneum and rectum in front. The superior hypogastric plexus extends on to the promontory, and below this the fascia of Waldeyer is attached. The midline of the sacral hollow contains the median sacral artery and vein, with some lymph nodes alongside them (p. 380). On each side the sacral sympathetic trunk crosses alongside the promontory to lie *medial* to the sacral foramina. Lateral to the foramina lies the sacral plexus on the piriformis muscle. The plexus and muscle are covered by a dense sheet of parietal pelvic fascia, on

which the lateral sacral artery and vein lie lateral to the foramina (Fig. 5.55, p. 378).

Dorsal surface

This convex surface is irregular and rough (Fig. 6.82). In the midline it is closed by fusion of adjacent laminae. The gap above, the *sacral canal*, due to the caudal slope of the first sacral laminae, is closed by the ligamenta flava attached to the laminae of L5 vertebra. The *sacral hiatus* below, variable in its extent, indicates failure of fusion of the laminae of S5 and often of S4 vertebrae. This hiatus is closed by fibrous tissue forming the superficial sacrococcygeal ligament. Adjacent spinous processes are fused with each other to produce a midline ridge, the *median sacral crest*, that projects dorsally from the fused laminae. The superior articular process on S1 vertebra carries a concave cylindrical facet for the synovial joint with L5 vertebra. Below this, medial to the posterior foramina and at the lateral margin of the fused laminae, is a line of irregular tubercles that represent fusion of adjacent articular processes of the sacral vertebrae. This low ridge forms the *intermediate sacral crest* and it is projected below, alongside the sacral hiatus, to end in the rounded *sacral cornu*, for articulation with the coccyx. Lateral to the superior

articular process is a prominent boss of bone which is the transverse process of S1 vertebra. Below this the transverse processes are fused with each other, making a ridge, the *lateral sacral crest*, lateral to the posterior foramina; its lower part is in line with the ridge on the posterior end of the iliac crest. It is marked by bosses of bone that represent the tips of the fused transverse processes. Thus the posterior sacral foramina are enclosed wholly by the fused sacral vertebrae, for the fused costal elements lie lateral to the lateral sacral crest. The groove between the median and lateral sacral crests is filled by erector spinae, and the posterior layer of the lumbar fascia that covers it is attached to both crests. Between the lateral sacral crest and the auricular surface the presence of three or four deep fossae gives an undulating irregularity to the lateral mass. The whole of this area carries the attachments of the weight-bearing sacroiliac ligaments. The *auricular surface* extends to the lateral border of the pelvic surface and ala. Broad above and narrow below, the articular cartilage has an irregular surface from tubercles and depressions in the bone itself.

Below the weight-bearing postauricular surface the sacrum is more slender, and the lateral crest meets the lateral border of the sacrum at the level of S4 vertebra. This point is the apex of a small triangular area below

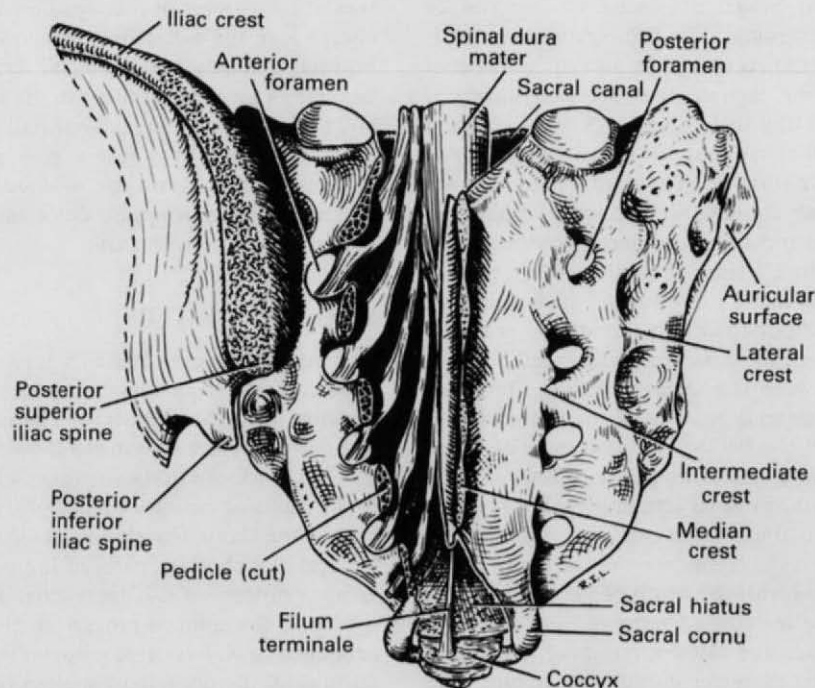


Fig. 6.82 Sacrum from behind. The five pedicles and laminae have been cut through on the left to show the sheaths of dura mater around the nerve roots.

the auricular surface. Part of the sacrotuberous ligament with its attached gluteus maximus arises from the triangular area (Fig. 3.55, p. 218). Below this the lateral margin of the sacrum gives attachment to the sacrospinous ligament and the coccygeus muscle. The apex of the sacrum is attached by an intervertebral disc to the body of the coccyx, and the cornua in some cases make tiny synovial joints with the cornua of the coccyx.

The *ala* of the sacrum projects laterally from the upper surface of S1 vertebra (Fig. 6.82). Its margin forms the brim of the pelvis. Laterally it gives attachment to the weak ventral sacroiliac ligament, and iliacus arises from the ligament over the ala. The base of the ala is crossed by the sympathetic trunk. Lateral to this, on the ala, lie the lumbosacral trunk medially, the obturator nerve laterally, and the ilio-lumbar artery between them.

Fusion of S1 and 2 vertebrae may be incomplete and they may articulate on one or other side after the manner of lumbar vertebrae, producing unilateral 'lumbarization' of S1 vertebra.

The **sacral canal**, triangular in cross section, curves with the sacrum. It is closed in front and behind. Pedicles project back from the upper half of each sacral body, making four intervertebral foramina which provide lateral exits as in the rest of the vertebral canal. But these exits are blocked further out by the lateral mass, which must be circumvented via anterior or posterior sacral foramina. The fifth sacral foramen is formed behind by the cornua of the sacrum and coccyx (Fig. 6.82) and the lateral sacrococcygeal ligament; emerging here are the insignificant S5 and coccygeal nerves. The sacral canal contains the meninges which extend down to S2 vertebra. The dura mater supports the arachnoid and contains cerebrospinal fluid, the roots of the sacral and coccygeal nerves and the filum terminale. The dura mater is prolonged as tubular sheaths around the sacral nerve roots, which unite just distal to the spindle-shaped bulgings of the posterior root ganglia. Each of these *lies just inside its own intervertebral foramen* between the sacral pedicles. The filum terminale, piercing the dura, runs down to blend with the periosteum on the back of the coccyx. The space around the dura mater and its prolongations is filled with loose fat and the internal vertebral venous plexus.

Sex differences in the sacrum are pronounced. The most useful guide is the comparison of the width of the body of S1 vertebra with the width of the lateral mass, or ala. In the male the rugged vertebrae and narrower pelvis, in the female the slender vertebrae and broad pelvis, imprint their characteristics on the sacrum. The body is wider than the ala in the male, narrower than the ala in the female (Fig. 6.83). Other differences lie in

the curvature of the bone. In the male the anterior surface is gently and uniformly concave; in the female it is flat above and turns forward more prominently below. The auricular surface occupies two and a half vertebrae in the male, only two in the female (who has more potential mobility at the sacroiliac joint).

Coccyx

This represents in man the multijointed tail of other vertebrates. It is contracted into four pieces fused together into a small triangular bone joined by its base to the apex of the sacrum at the *sacrococcygeal joint* (p. 414). This is a small midline symphysis with a fibrocartilaginous disc (but occasionally it is a synovial joint), reinforced by certain ligaments. The *ventral* and the *deep dorsal sacrococcygeal ligaments* lie at the front and back respectively (the *superficial dorsal ligament* covers over the sacral hiatus — p. 553), and at each side there is a *lateral sacrococcygeal ligament* joining the transverse process of the first piece of the coccyx to the inferolateral angle of the sacrum. This lateral ligament completes the foramen for S5 nerve and is sometimes ossified on one or both sides. In examinations, beware of the sacrum with five foramina on one or both sides instead of the normal four! It could have this ossified ligament at the lower end or there could be sacralization of L5 vertebra at the top. The upper surface of the coccyx is in the pelvic floor, the lower surface is in the buttock, beneath the skin of the natal cleft. The tip of the coccyx gives attachment to the anococcygeal raphe and to the intermediate (superficial) part of the external anal sphincter. Its borders give attachment to the coccygeus muscle and sacrospinous ligament, and to the overlapping posterior fibres of iliococcygeus and pubococcygeus (levator ani).

CERVICAL VERTEBRAE

The cervical column makes a forward convexity. The widest of the transverse processes are those of C1 vertebra, the atlas (Fig. 6.6). The most massive of the spinous processes is that of C2 vertebra, the axis; but this is not noticed in the living neck because it lies deep in the extensor muscles beneath the projecting occipital pole of the skull. The change of curvature between the cervical and thoracic parts of the column projects the spinous process of C7 backwards. The prominence of the tip of the spinous process gives the name *vertebra prominens* to C7 vertebra — but it is fallacious to count on this, for the uppermost spinous process to be visible or readily palpable may be that of T1 vertebra. The atlas and axis are adapted to the functions of head

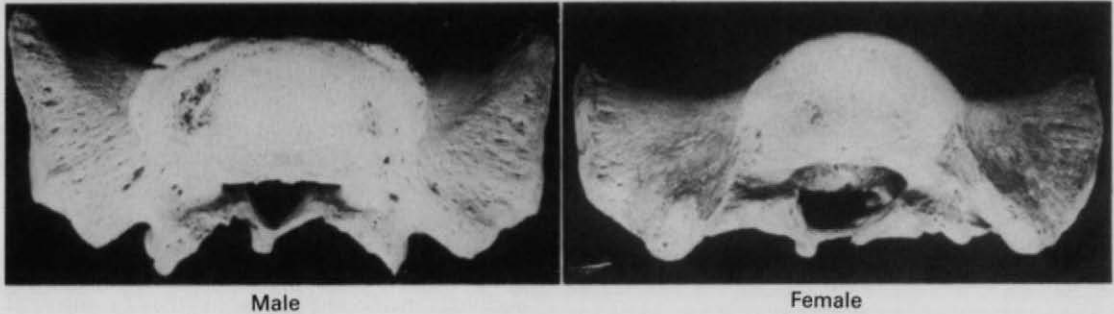


Fig. 6.83 Male and female sacrum from above. In the male the body of the first sacral vertebra is broad and the alae narrow; in the female the body is narrow and the alae broad.

nodding and rotation and C7 has certain peculiar characteristics, so there are only four 'typical' cervical vertebrae, C3–6.

A typical cervical vertebra

The broad kidney-shaped *body* is the same size as, or smaller than, the vertebral foramen (Fig. 6.84). On each side it is projected up into a posterolateral lip or *uncus*, and its lower margin laterally is bevelled reciprocal with this. In the midline the lower margin is projected downwards a little. The flat upper and lower surfaces, each covered by a plate of hyaline cartilage, give attachment to the intervertebral disc. This flat area is the centrum of the vertebra. The upturned lips and bevelled margins are on the (morphological) neural arch. The hyaline cartilage on the centrum continues across these surfaces lateral to the disc attachments. The basivertebral foramina on the posterior surface are wider apart than in thoracic and lumbar vertebrae. Basivertebral veins emerge from them, and the posterior longitudinal ligament spans the veins. The anterior surface of the body is concave from above down, and the anterior longitudinal ligament is firmly attached to this surface. Longus colli overlies the ligament.

The *pedicle* is attached below the upturned lip on the body. Thus an intervertebral foramen in the neck is bounded in front by *both* vertebral bodies and the uncovertebral joint and disc between them (Fig. 6.85). Contrast the foramina lower down, where the anterior boundary is the intervertebral disc and the body above it (Figs 6.77 and 6.78). Attached to the pedicle and body is the lateral projection of the transverse process, perforated by its foramen. The proximal part of the posterior bar of bone that projects from the pedicle behind the foramen is the *true transverse element*, and it ends in the posterior tubercle, which is part of the costal element. The bar of bone that projects from the body in

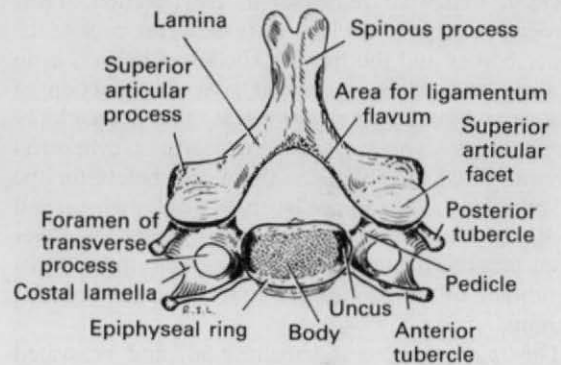


Fig. 6.84 C6 vertebra from above.

front of the foramen ends in the upturned anterior tubercle. The anterior tubercles enlarge progressively from C3 to C6. The large C6 anterior tubercle is the *carotid tubercle* (of Chassaignac) because the common carotid artery can be compressed against it (a former method of producing unconsciousness). The anterior and posterior tubercles are joined by a down-curved plate of bone, the *intertubercular lamella* (frequently but wrongly called the costotransverse bar) (Fig. 6.84). The anterior bar and tubercle, the lamella and the posterior tubercle with the adjacent part of the posterior bar form the costal element, a vestigial rib fused to the vertebra. The vertebral artery lies in the foramen of the transverse process, and the posterior root ganglion of the nerve of the same number lies behind it on the lamella (Fig. 6.96). The anterior tubercle gives attachment to the tendons of longus capitis, scalenus anterior and longus colli (Fig. 6.6). The posterior tubercle gives origin to scalenus medius. Levator scapulae arises from the posterior tubercles down to C4, and scalenus posterior from those of C5 and 6 (and 7).

The *laminae* enclose a relatively large *vertebral*

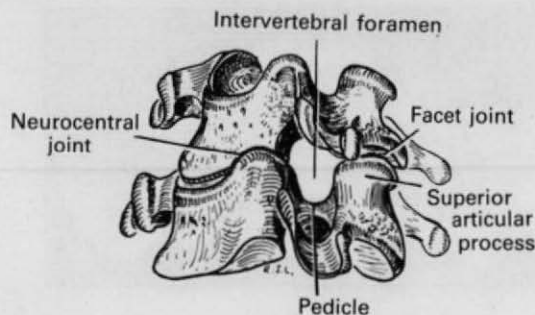


Fig. 6.85 C3 and C4 vertebrae articulated to show the boundaries of the intervertebral foramen.

foramen, somewhat *triangular* in cross-section. Their borders are grooved for ligamenta flava (the back of the upper border and the front of the lower border, as in thoracic and lumbar vertebrae). At the junction of pedicle and lamina there are *superior* and *inferior articular processes*. The two processes form a cylindrical column sliced off obliquely above and below for the articular facets. The upper facets face obliquely up and back, and usually both lie in the same plane. The lower facets face down and forward. The capsule and synovial membrane of these joints are attached to the articular margins.

The *spinous process* is usually bifid, and excavated inferiorly by a pair of concavities for semispinalis cervicis.

Atypical cervical vertebrae

The **seventh cervical vertebra** is often called the *vertebra prominens* because of its prominent spine but this may be a misnomer (p. 554). The vertebra is atypical in that its long spine is not bifid but ends in a rounded tubercle, and the foramen in the transverse process does not transmit the vertebral artery. The foramen is small, and contains the posterior vein when the vertebral vein is doubled. It is said to transmit the grey ramus from the inferior cervical ganglion to the anterior ramus of C7, but this is doubtful. The anterior tubercle is very small; to it are attached scalenus pleuralis and the suprapleural membrane (Fig. 4.5, p. 247).

Atlas

The essential features are summarized on page 541. A glance at the articular facets serves to distinguish upper from lower surfaces. The kidney-shaped facets for the occipital bone (Fig. 6.86) are deeply concave from front to back, and the two together make a more gentle

concavity from side to side. In the 'hilum' of each 'kidney' is a tubercle for attachment of the vital transverse ligament, which stabilizes the dens (odontoid process) of the axis.

The *anterior arch* is short and its posterior concave surface carries a concave cylindrical facet for the synovial joint with the dens. It is projected into a *tubercle* in front (Fig. 6.86), for attachment of the anterior longitudinal ligament and longus colli. The upper border of the arch carries the anterior atlanto-occipital membrane between the capsules of the atlanto-occipital joints. The *posterior arch* is longer, and makes almost a semicircle. At the root of the arch the upper surface is grooved, below the projecting articular facet, by the vertebral artery and C1 nerve (p. 547). The groove is an unreliable guide for orientation of the disarticulated atlas, because it is often very shallow, and the under surface may show a similar groove for the posterior root ganglion of C2 nerve. The upper border of the posterior arch gives attachment to the posterior atlanto-occipital membrane between the arterial grooves, while the lower border receives the ligamentum flavum from the axis. A pair of dimples at the posterior convexity of the arch give origin to the rectus capitis posterior minor muscles. The *lateral mass* carries the weight-bearing *articular facets*. In contrast to the deep concavity of the upper kidney-shaped surfaces the lower facets are circular and flat, or very gently concave. They articulate with the superior articular facets of the axis. The lateral mass is projected into the *transverse process*, which is perforated by the foramen. There is usually no distinct formation of anterior and posterior tubercles, but all the bone anterior and lateral to the vertebral foramen is costal in origin.

The internal jugular vein, crossed by the accessory nerve, lies on the transverse process. Posteriorly the transverse process gives attachment to obliquus capitis

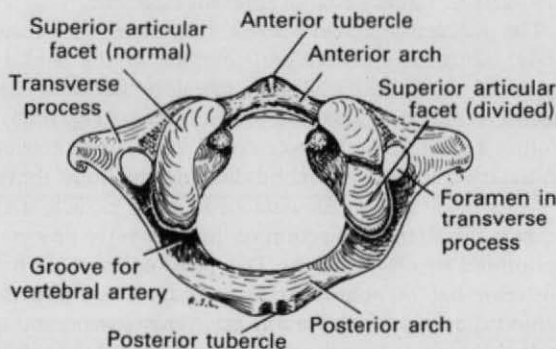


Fig. 6.86 Atlas from above.

superior and inferior, to splenius cervicis, and to levator scapulae. Anteriorly the little rectus capitis anterior and lateralis are attached to the lateral mass (Figs 6.6 and 6.75).

Axis

C2 vertebra provides the pivot around which the atlas and head rotate. The dens (odontoid process) is quite characteristic, projecting up from the body between a pair of massive weight-bearing shoulders on the lateral mass (Fig. 6.70). The weight is communicated from these shoulders through the body to the body of C3 vertebra; the articulations between C2 and 3 vertebrae are typical of the rest of the column.

The *dens* (*odontoid process*) carries anteriorly a cylindrical facet which makes a synovial joint with the anterior arch of the atlas. Its posterior surface is usually smooth, but no synovial joint exists here, only a bursa to lubricate the movements of the transverse ligament during head rotation. The apex of the dens carries the apical ligament (a remnant of the notochord) and the borders that slope down from the apex give attachment to the alar ligaments, one on either side. The *body* shows the bevel along the lateral margin of its lower surface typical of the cervical vertebrae, and in the midline the lower margin projects down a little. The lower surface articulates typically with C3 body by a disc.

The anterior longitudinal ligament is attached to the front of the *body*, with longus colli and the prevertebral fascia overlying it. The posterior surface of the body gives attachment to the longitudinal band of the cruciform ligament and, below it, to the tectorial membrane which sweeps up from the attachment of the posterior longitudinal ligament. The upper surface of the body carries a pair of large *facets*. These slope down from the dens like shoulders (Fig. 6.87), and each extends from the body well back onto the massive pedicle and well out on the lateral mass, where it overhangs the foramen in the transverse process (Fig. 6.70). Each surface makes a synovial joint with the facet on the under surface of the lateral mass of the atlas. The costal element slopes steeply down from the body to end in a prominent *transverse process*. This represents the posterior tubercle of a typical cervical vertebra. The *foramen* in the transverse process is not vertical as in the other vertebrae, but is directed upwards and outwards to communicate a lateral bend to the vertebral artery (Fig. 6.96). Scalenus medius, splenius cervicis and levator scapulae are attached to the transverse process. An inferior articular process extends down from the junction of pedicle and lamina; its articular facet faces

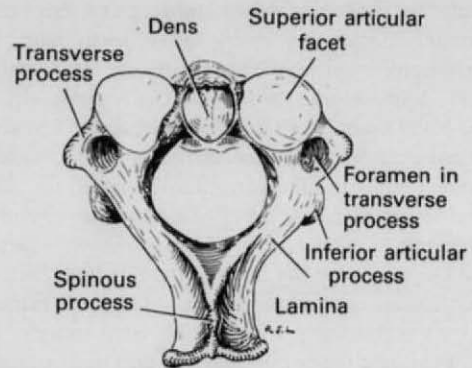


Fig. 6.87 Axis from above.

downwards and forwards as in typical cervical vertebrae (Fig. 6.70). The *laminae* are thick and rounded and project posteriorly into a massive *spinous process* (Fig. 6.87). The upper border of this is ridged, but the lower surface is grooved and ends in a wide bifurcation, so the tip of the spinous process resembles an inverted U (Fig. 6.75). The pair of strong semispinalis cervicis muscles are inserted into the concavity, while rectus capitis posterior major and the inferior oblique diverge widely from the outer surface on either side. The thick rounded upper and lower borders of the laminae give attachment to the ligamenta flava. The posterior surface of the laminae carries multifidus and longissimus attachments.

Movements of vertebrae

These are discussed on page 540.

DEVELOPMENT OF VERTEBRAE

The vertebrae develop from the sclerotome parts of the mesodermal somites (p. 36). The sclerotomes surround the notochord and neural tube in a sheath of mesoderm. A series of cartilaginous rings appears in the mesodermal sheath; each ring ossifies in three centres to form the centrum and the two halves of the neural arch of a vertebra. Each ring (and the vertebra to which it gives rise) is formed by fusion of adjacent halves (caudal and cranial) of the original somites. Thus the vertebrae lie not in segments of the body wall, but in the intersegmental planes.

All the vertebrae **ossify** in hyaline cartilage. The centre for the centrum is double, but the two areas rapidly fuse; failure of one half results in hemivertebra. The centrum and the two halves of the neural arch are ossified by the eighth week of fetal life. The cartilage

between the two halves of the neural arch (i.e. between the laminae) begins to ossify after birth and is completely bony in all vertebrae by the age of 2 years. Then the neurocentral junctions ossify and there should be bony union in all by about the age of 7 years. The vertical cylindrical surface of the body is covered with compact bone, but the cancellous bone on the flat upper and lower surfaces, bevelled around its circumference, remains covered with a layer of hyaline cartilage. The epiphyses for the body appear as bony rings, upper and lower, soon after puberty. They are ridged and grooved reciprocally with the bevelled margin of the body. Fusion of the epiphyseal ring and body occurs in the early twenties. Thus the vertebra of an adolescent, when macerated and separated from its annular epiphysis, shows irregular radial grooves at the circumference of upper and lower surfaces (Fig. 6.88).

Soon after puberty secondary centres appear also at the tip of the spinous process (double in the bifid spines of the cervical vertebrae) and at the tips of the transverse processes of all the vertebrae, and in the mamillary processes of T12 and the lumbar vertebrae. These fuse in the early twenties. It is noteworthy that the costal elements of cervical and lumbar vertebrae do not have a separate bony centre, but ossify by direct extension from the neural arch. An occasional centre in the costal element of C7 or L1 vertebra may lead to the formation of a cervical or lumbar rib. On the other hand the weight-bearing costal elements of the sacrum have bony centres. These appear at 6 months of fetal life and fuse with the



Fig. 6.88 L5 vertebra from above. The neurocentral junction has not yet completely ossified. The radial grooves around the anterolateral convexity of the body indicate that the epiphyseal ring had not united.

neural arches at about 5 years. They fuse with each other and with the sacral bodies in the early twenties.

The **atlas** ossifies in the seventh week by a centre in each lateral mass. These extend around the posterior arch and unite at the fourth year. In the meantime a centre in the anterior arch has appeared at the first year. Its junction with the bone of the lateral mass cuts across the anterior part of the upper articular surface; these epiphyses fuse at 7 years. This epiphyseal junction may permanently divide the articular surface (as in Fig. 6.86, right side).

The **axis** has primary centres for the lower part of the body (fifth month) and each half of the arch and lateral part (seventh week), and also one centre for each half-side of the dens extending to the upper part of the body (fifth month, fusing to form a single centre 2 months later), and uniting, like the lateral parts, with the rest of the body at 3 years. There is a secondary centre for the tip of the dens, appearing at about 3 years and fusing at 12, and an epiphyseal ring for the lower part of the body, appearing at puberty and fusing at about 25 years.

PART 21

CRANIAL CAVITY AND MENINGES

The interior of the cranium is lined with *dura mater*, the surface of the brain is covered with *pia mater*. Between the two, in contact with the *dura mater*, lies the *arachnoid mater*, which is connected to the *pia* by many fine filamentous processes (hence the name *arachnoid* — spiderlike). The region between the *arachnoid* and *pia* is the *subarachnoid space*, filled with *cerebrospinal fluid*. These three tissue layers constitute the **meninges**. The *cranial* meninges are described here; their continuations around the spinal cord as the *spinal* meninges are considered on page 547.

GENERAL ARRANGEMENT

A stranded whale dies because it is too heavy to breathe; its weight must be permanently suspended in water (remember the Principle of Archimedes). The soft brain is similarly suspended in fluid; without this support it flops flat (observe sheep's brains on a slab in the butcher's shop). The cerebrospinal fluid in which the brain 'floats', effectively reducing its weight from 1500 g to 50 g, is held in a thin bag of *arachnoid mater*. This delicate membrane is cerebrospinal-fluid-proof, but not strong enough to withstand the hydrostatic

pressure, so it is supported everywhere by being in contact on its outer surface with dura mater. This is a tough sheet of thick fibrous tissue. In the vertebral canal it lies free, but supports the arachnoid mater — two wet surfaces in contact, with only a film of tissue fluid between them. In the cranial cavity the fibrous dura mater is largely fused with the periosteum that lines the skull bones; but whatever its contour it supports the arachnoid mater, which everywhere lies in surface contact with it. The surface of the brain itself, closely covered with a vascular fibrous membrane, the pia mater, fits snugly over its convexity against the arachnoid mater, but along its sulci and across its base it is out of contact with arachnoid mater. Here it 'floats' free in the cerebrospinal fluid.

PIA MATER

The **pia mater** invests the brain and spinal cord as periosteum invests bone. Like periosteum it contains blood vessels, and *nowhere does any structure intervene between pia mater and the underlying nervous tissue*. It invests the surface of the central nervous system to the depths of the deepest fissures and sulci. It is made of vascular fibrous tissue and can fairly easily be stripped away from the brain surface. It is prolonged out over the cranial nerves and spinal nerve roots to fuse with their epineurium, and it is invaginated into the substance of the brain by the entering cerebral arteries. The arteries lie loose in these sheaths of pia, surrounded by a narrow perivascular space containing cerebrospinal fluid. The pia mater of the spinal cord is projected laterally, on each side, to form the denticulate ligament (p. 575).

ARACHNOID MATER AND SUBARACHNOID SPACE

The **arachnoid mater** consists of an impermeable delicate membrane that everywhere is supported by the inner surface of the inner layer of the dura mater. *Nothing save a thin film of tissue fluid (lymph) lies between the two*, in the **subdural space**, throughout the whole extent of the cranial and spinal cavities, with the sole exception of the aqueduct of the cochlea (p. 532) where they are blended together. Vessels and nerves pierce the dura and arachnoid mater both at the same place, and never run along between the two membranes.

The relationship of dura and arachnoid is similar to that of parietal and visceral pleura, except that they do not become continuous with one another.

Beneath the arachnoid is the **subarachnoid space**. In some places over the convexity of the brain (e.g. the

gyri on the superolateral surface of the cerebral hemispheres) the space is obliterated by fusion of pia and arachnoid (so giving rise to the term 'pia-arachnoid'), but mostly the two are separate with only delicate web-like strands connecting the two. In the spinal part of the space these strands are condensed into a thin posterior midline lamina that forms the incomplete *posterior median septum*. The subarachnoid space provides a pathway for the circulation and absorption of cerebrospinal fluid after its escape from the fourth ventricle (p. 613).

Structures connecting the surface of the brain with foramina necessarily pass through the subarachnoid space. Thus all the cranial nerves and the roots of the spinal nerves traverse the space, as well as all the arteries and veins of the brain and spinal cord. The space extends down to the termination of the spinal arachnoid and dura at the level of S2 vertebra.

In certain areas the arachnoid herniates through little holes in the dura mater into the venous sinuses. Such herniae are the **arachnoid villi**; through their walls the cerebrospinal fluid 'oozes' back into the blood. The arachnoid villi are most numerous in the superior sagittal sinus and its laterally projecting blood lakes. In the child the villi are discrete; as age progresses they become aggregated into visible clumps, the **arachnoid granulations (Pacchionian bodies)**. These latter leave indentations on the inner table of the cranial vault alongside the superior sagittal sinus, at the site of the blood lakes (Fig. 7.16, p. 599).

Between the base of the brain and the base of the skull several larger spaces exist as a result of the incongruities in the contours of bone and brain. These spaces form the **subarachnoid cisterns**.

The **cerebellomedullary cistern (cisterna magna)** is the largest. It occupies the angle between the under surface of the cerebellum and the posterior surface of the medulla. Cerebrospinal fluid flows into it from the midline aperture (foramen of Magendie) in the roof of the fourth ventricle (p. 613). The lateral part of the cistern contains the vertebral artery and its posterior inferior cerebellar branch on each side (Fig. 7.23, p. 605). The cisterna magna can be tapped in the midline by a needle passed through the posterior atlanto-occipital membrane and spinal dura.

The **pontine cistern** lies between the clivus and the front of the pons and medulla. Cerebrospinal fluid flows into it from the lateral apertures (foramina of Luschka) of the fourth ventricle (p. 613). The cistern contains the basilar artery and its pontine and labyrinthine branches and the fifth to twelfth cranial nerves.

The **interpeduncular cistern** lies between the dorsum sellae and the cerebral peduncles; it is roofed in by the floor of the third ventricle (mamillary bodies and posterior perforated substance). The floor of the cistern, on the dorsum sellae, is formed by the arachnoid membrane passing across, in contact with the dura mater, between the right and left temporal lobes. The cistern contains the terminal branches of the basilar artery (including the posterior part of the circle of Willis), the stalk of the pituitary gland, and the third and fourth cranial nerves (Fig. 7.23, p. 605).

The **chiasmatic cistern** lies above the optic chiasma, beneath the rostrum of the corpus callosum. It contains the anterior communicating artery and the intracranial part of the optic nerves.

DURA MATER

The dura mater is conventionally described as consisting of outer and inner layers. (The outer is often called the endosteal layer, and the inner the fibrous or meningeal layer, but there is no need for these somewhat confusing alternatives; all are fibrous and all are part of the meninges.) However, the two-layer concept is to some extent a false one, since the **outer layer** is none other than the **periosteum** which invests the surface of any bone. Blood vessels pass through it to supply the bone, but no structure intervenes between it and the bare bone, similar to the arrangement of periosteum anywhere else in the body. Around the margins of every foramen in the skull it lies in continuity with the periosteum on the outer surface of the cranial bones (pericranium). It is not prolonged into the dura mater of the vertebral canal nor is it ever invaginated by any cranial nerve. It is ordinary periosteum and never leaves contact with bone.

The **inner layer** is very different. It consists of a dense, strong fibrous membrane, which is really the dura mater proper. In most places it is intimately fused with the outer layer and cannot be separated from it even by sharp dissection. Over the vault of the skull the fused layers are easily stripped away from the bone as a single sheet, a fact which makes removal of the vault relatively easy. Over the base of the skull the fused layers are so firmly attached that they can only be stripped off with difficulty. Although theoretically structures such as the middle meningeal vessels (p. 562) lie between the two layers, they appear to be on the outer surface of this single sheet (as when the bone of the skull vault is removed leaving the dura intact), and so are usually described as being extradural. Strictly speaking, this means outside the outer layer, but the vessels are thicker than the outer layer and so bulge out

to make impressions on the bone with a negligible amount of intervening tissue. Haemorrhage from these vessels is described as extradural (p. 568).

However, in other places the inner layer is separated from the outer to form the *venous sinuses* of the dura mater, which thus lie between the two layers (Fig. 6.89). Also, folds of the inner layer project into the cranial cavity. One such fold, the *tentorium cerebelli*, roofs in the posterior cranial fossa; another forms the *falx cerebri*, lying in the midline between the two cerebral hemispheres. The *falx cerebelli* and *diaphragma sellae* are smaller derivatives of the inner dural layer; all four folds are described below. The function of these fibrous flanges or septa is to minimize rotary displacement of the brain. Concussion is caused more readily by rotary movement of the brain rather than by mass displacement of the head. Finally, at the foramen magnum the inner layer leaves the outer layer and is projected down the vertebral canal as the spinal dura mater (p. 574). The inner layer is likewise evaginated around the cranial nerves and spinal nerve roots. In places these evaginations pass straight out, as around the spinal nerve roots; in other places they lie between the two layers of the dura, as in the trigeminal (Meckel's) cave.

The **tentorium cerebelli** is a flange of the inner layer which projects from the margins of the transverse sinuses and the margins of the superior petrosal sinuses (Fig. 6.89). It is attached to the posterior clinoid processes along the upper borders of the petrous temporal bones and horizontally along the inner surface of each side of the skull to the internal occipital protuberance; this is the *attached margin* of the tentorium. Its upper and lower layers are separated at their bony attachments by the superior petrosal and transverse sinuses, but elsewhere are intimately fused with each other. There is no venous sinus in the *free margin* of the tentorium which is U-shaped and lies at a higher level than the bony attachment. The large central gap is the *tentorial notch*, through which passes the upper part of the brainstem (midbrain). The membrane slopes concavely upwards as it converges from the attached to the free margin, in conformity with the shape of the upper surface of the cerebellum and the under surface of the posterior part of the cerebral hemisphere.

The concave free margin is traceable forwards to the anterior clinoid process on each side. Over the superior petrosal sinus it overlies the attached margin, and from this point forwards to the anterior clinoid process it lies as a ridge of dura mater on the roof of the cavernous sinus. To the medial side of the ridge is the concave triangular roof of the cavernous sinus (p. 564) which is pierced by the third and fourth nerves.

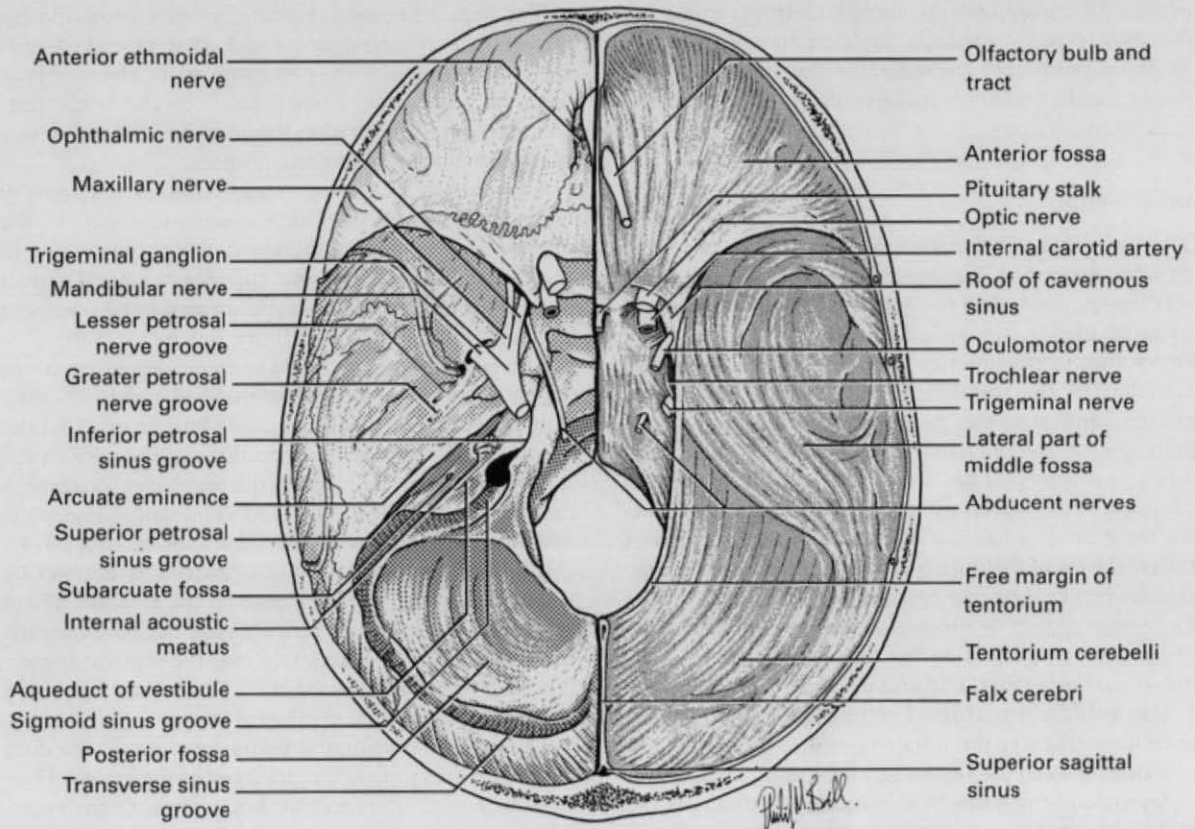


Fig. 6.89 Cranial fossae. Much of the dura mater has been removed but the right half of the tentorium cerebelli has been preserved.

The midline attachment of the falx suspends the tentorium, which falls down if the falx is divided (e.g. at autopsy). The straight sinus, which lies in the midline at the junction of the two, slopes more steeply than 45° in the intact dura mater (Fig. 6.19).

The **falx cerebri** is a sickle-shaped flange of the inner layer in the midline between the cerebral hemispheres. Its anterior margin is attached to the crista galli of the ethmoid bone and to the cavity of the foramen caecum, into which it projects like a peg — an enlarged Sharpey's fibre. The posterior margin is attached to the upper surface of the tentorium cerebelli in the midline, from the attached to the free margin of the tentorium; here its layers are separated for the passage of the straight sinus. Its convex upper border is attached alongside the midline to the whole length of the concave inner surface of the skull, from the foramen caecum to the internal occipital protuberance. Its two layers are separated a short distance above the foramen caecum to accommodate the *superior sagittal sinus*,

which becomes progressively broader from this point to the internal occipital protuberance. The concave lower border of the falx cerebri is free and contains the *inferior sagittal sinus* within its two layers; this border lies just above the corpus callosum (Fig. 7.20, p. 602). Between superior and inferior sagittal sinuses the two layers of the falx are firmly united to form a strong inelastic membrane.

The **falx cerebelli** is a low elevation of the inner layer in the midline of the posterior cranial fossa, extending from the internal occipital protuberance along the internal occipital crest to the posterior margin of the foramen magnum. It lodges the small *occipital sinus* between its layers, and it projects a little into the sulcus between the cerebellar hemispheres.

The **diaphragma sellae** is a horizontal sheet of the inner layer that forms a roof for the pituitary fossa (p. 569). The dura of the floor of the fossa is prolonged up the sides of the fossa, hitched between the middle and posterior clinoid processes, to form a flange lying

between the fossa and the cavernous sinus. From this the dura extends medially to form the diaphragma, which is perforated centrally for the passage of the *pituitary stalk*, and flows out laterally to form the roof of the cavernous sinus.

Blood supply

The inner layer of the dura mater requires very little blood to nourish it. The outer layer, on the other hand, is richly supplied, with the adjacent bone. In the supratentorial part it is supplied by the middle meningeal artery and, in the anterior cranial fossa, by meningeal branches of the ophthalmic and anterior ethmoidal arteries, and over the cavernous sinus by meningeal branches of the internal carotid and the accessory meningeal artery. The latter vessel enters the skull, from the maxillary artery, through the foramen ovale. All these arteries lie, like the venous sinuses, between the two layers of the dura (p. 560). In the posterior fossa arteries run in the same plane, which they enter at the foramen magnum as meningeal branches of the vertebral artery given off, of course, before this vessel pierces the spinal theca (Figs 6.90 and 6.96).

The **middle meningeal artery**, a branch of the maxillary, arises in the infratemporal fossa and passes upwards between the two roots of the auriculotemporal nerve to enter the foramen spinosum. It thus enters the middle cranial fossa, accompanied by its own plexus of sympathetic nerves. It is accompanied throughout all its ramifications by veins which lie between it and bone and which are responsible for the grooves indented on the inner surface of the skull. It courses laterally on the floor of the middle cranial fossa and turns upwards and forwards on the greater wing of the sphenoid, where it divides into anterior and posterior branches.

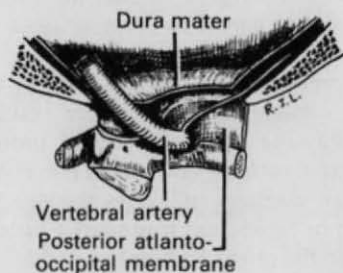


Fig. 6.90 Right half of the foramen magnum viewed from within. The vertebral artery, having pierced the posterior atlanto-occipital membrane, gives off meningeal branches before piercing the dura mater to enter the subarachnoid space.

The *frontal (anterior) branch* courses up towards the pterion (p. 644) and then curves back to ascend towards the vertex, lying over the precentral gyrus. Haemorrhage from the vessel thus causes pressure on the motor area. In the region of the pterion the artery frequently lies in a bony tunnel for a centimetre or more.

The *parietal (posterior) branch* courses horizontally backwards, on a groove in the squamous part of the temporal bone, and ramifies over the posterior part of the skull. It lies along the superior temporal gyrus; haemorrhage here may cause contralateral deafness through pressure on the auditory area (see p. 586).

The purpose of the middle meningeal artery is to supply the bones of the vault of the skull; *it does not supply the brain*. These bones receive very little blood from the vessels of the scalp; scalping produces no necrosis of the underlying bones. Only where the bones give attachment to muscles (temporal fossa and suboccipital region) is any substantial supply received from the exterior.

Much of the blood from the marrow is drained by large *diploic veins*, which emerge on the exterior. There are one frontal, two parietal, and one occipital on each side. Other diploic veins drain into the venous sinuses, especially the superior sagittal. The remaining blood drains into the middle meningeal veins.

The **middle meningeal veins** are *sinuses* in the dura mater and accompany the branches of the artery. They lie between the artery and the bone, grooving the latter. Some converge to two veins which leave the skull through the foramen spinosum and foramen ovale to join the pterygoid plexus. Most middle meningeal veins join the sphenoparietal sinus.

The **surface markings** of the middle meningeal artery are important in the matter of trephining for haemorrhage. The marking for the foramen spinosum, where the vessel enters the skull, lies at a level just above the articular eminence at the posterior root of the zygomatic arch, but more important is the marking for the frontal branch which is surgically approached through a burr hole at the pterion, which is 3 cm above the midpoint of the zygomatic arch (behind and above the frontozygomatic suture). The posterior branch runs backwards parallel with the upper border of the zygomatic arch and the supramastoid crest; it is usually exposed vertically above the mastoid process on a level horizontal with the upper margin of the orbit.

Nerve supply

Most of the supratentorial part of the dura mater is supplied, rather surprisingly, from the ophthalmic division of the trigeminal nerve. The *tentorial nerves* course up and back from the anterior end of the

cavernous sinus to supply the falx, the dura of the vault, and the upper surface of the tentorium cerebelli. The anterior cranial fossa receives some twigs from the anterior ethmoidal and maxillary nerves.

The middle fossa is supplied, in its anterior portion by a branch of the maxillary division of the trigeminal (the middle meningeal nerve), and in its posterior part by the meningeal branch of the mandibular nerve (nervus spinosus).

The posterior fossa is supplied by meningeal branches of the ninth and tenth cranial nerves. These innervate the under surface of the tentorium cerebelli and the upper part of the bony fossa, but the dura around the foramen magnum is supplied by the upper three cervical nerves, indicating an upward migration of spinal dura to invest the outsize brain of man (like the upward migration of the skin to cover the skull and face, p. 450). Clinical experience suggests that this cervical supply extends farther afield than the boundaries of the foramen magnum; cervical spondylosis, for example, may be associated with deep-seated pain in the orbit, presumably referred from spinal nerves.

VENOUS SINUSES OF THE DURA MATER

All the venous sinuses, except the inferior sagittal and straight sinuses, lie between the inner and outer layers of the dura. They receive all the blood from the brain, and with the above exceptions they receive blood also from the adjacent bone. Several of them have important communicating branches with veins outside the skull.

The venous sinuses are held permanently open by the unyielding inner dura mater. Provided the head is above the heart they drain into the jugular veins by a siphonage effect (e.g. with the head nodding forwards, blood in the superior sagittal sinus flows *upwards* from the forehead against gravity). Internally, like all vascular channels, they are lined by endothelium. They do not contain valves.

The **superior sagittal sinus** lies between the two layers of the falx cerebri along the convexity of its attached margin. It commences just above the foramen caecum and grows progressively larger as it passes back to the internal occipital protuberance. It grooves the bones along the midline of the vault of the skull. Three or four lakes of blood project laterally from it, between the inner dura and the endosteum; into these lakes the arachnoid granulations project to return cerebrospinal fluid to the bloodstream (Fig. 7.16, p. 599).

The arachnoid granulations leave indentations on the adult skull. The superior sinus does not drain the frontal pole of the hemisphere, but receives veins from

the upper and posterior parts of both medial and lateral surfaces of both hemispheres. These superior cerebral veins enter the sinus obliquely, against the flow of the bloodstream. The superior sagittal sinus turns at the internal occipital protuberance, generally to the right, and becomes the transverse (lateral) sinus (Fig. 6.89).

The **inferior sagittal sinus** begins some little distance above the crista galli and lies between the folds of the free margin of the falx cerebri. It drains the lower parts of the medial surface of each hemisphere. At the attachment of falx cerebri and tentorium cerebelli it flows into the straight sinus (Fig. 7.20, p. 602).

The **straight sinus** lies between the folds of the fibrous dura at the junction of falx cerebri and tentorium cerebelli. It commences anteriorly by receiving the inferior sagittal sinus, the right and left basal cerebral veins and the single great cerebral vein (of Galen). The straight sinus also receives veins from the adjoining occipital lobes and from the upper surface of the cerebellum. It ends at the internal occipital protuberance by turning into the transverse (lateral) sinus, generally the left. The straight sinus slopes down steeply, at more than 45° (Fig. 6.19).

The **transverse sinus** commences at the internal occipital protuberance and runs laterally between the two layers of the attached margin of the tentorium cerebelli (Fig. 6.89). It courses horizontally forwards, grooving the occipital bone and the mastoid angle of the parietal bone. Reaching the junction of petrous and mastoid parts of the temporal bone it curves downwards, deeply grooving the inner surface of the mastoid bone, as the sigmoid sinus. One sinus is larger than the other, namely that which receives the superior sagittal sinus; this is usually the right. It should be noted that in clinical work the transverse and sigmoid sinuses are often referred to by their old name of *lateral sinus*.

The two transverse sinuses communicate at their commencement at the internal occipital protuberance (*confluence of the sinuses*). Each receives tributaries from the nearby surfaces of cerebral and cerebellar hemispheres and, at its termination at the commencement of the sigmoid sinus, the superior petrosal sinus enters.

The *surface marking* of the transverse sinus is lower than is commonly thought. It runs horizontally from the external occipital protuberance to the top of the mastoid, that is, at the upper limit of the neck muscles where they join the skull, along the superior nuchal line.

The **sigmoid sinus** commences as the termination of the transverse sinus, deeply grooving the inner surface of the mastoid part of the petrous bone. It curves downwards and then forwards to the posterior margin of the jugular foramen (Fig. 6.89). Here it

expands into the *jugular bulb* which occupies the posterior and largest compartment in the jugular foramen, from which it emerges as the *internal jugular vein*. The sigmoid sinus is connected with the exterior in its upper part by the mastoid emissary vein which joins the posterior auricular vein, and in its lower part by a vein which passes through the posterior condylar foramen (when present) to join the suboccipital plexus of veins.

It receives the superior petrosal sinus at its upper end and the occipital sinus at its lower end. Cerebellar veins drain to it, and it receives veins also from the mastoid air cells. Thrombophlebitis in these veins may lead to cerebellar abscess from mastoid infection.

The **occipital sinus** runs downwards from the beginning of the transverse sinus to the foramen magnum, skirts the margin of the foramen and drains into the sigmoid sinus. The two sinuses, lying along the attachment of the falx cerebelli, are often fused into a single trunk. Around the margins of the foramen magnum the sinuses communicate with the veins outside the spinal dura (the internal vertebral plexus). The occipital sinus receives tributaries from the cerebellum and medulla and drains the choroid plexus of the fourth ventricle.

The **basilar sinuses** consist of a network of veins, lying between the two layers of the dura, on the clivus (Fig. 6.30). They connect the two inferior petrosal sinuses and receive veins from the lower part of the pons and from the front of the medulla. Thrombosis is thus fatal.

Note that no veins accompany the vertebral and basilar arteries; the vertebral vein itself commences *outside* the skull below the occipital bone (p. 547).

Cavernous sinus

The **cavernous sinus** lies alongside the body of the sphenoid bone in the middle cranial fossa (p. 568). Each contains the internal carotid artery (Fig. 6.91) and transmits some cranial nerves, each receives blood from three sources (orbit, vault bones, and cerebral hemisphere), each drains by three emerging veins (superior and inferior petrosal sinuses, and a small vein to the pterygoid plexus) and the two sinuses intercommunicate. Their position, relations and contents make them key structures in the topographical anatomy of the skull.

The cavernous sinus lies in a space between the periosteum of the body of the sphenoid (outer layer of the dura mater) and a fold of the inner layer. The fold commences medially, as the roof of the sinus, where the side wall of the pituitary fossa and the diaphragma sellae meet (p. 561). The *roof* is attached to the anterior

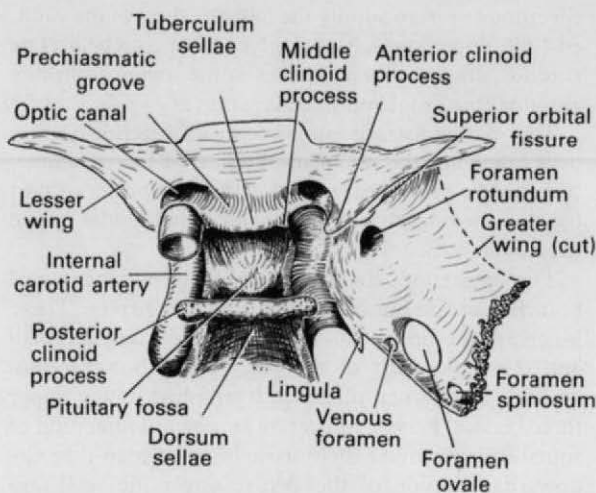


Fig. 6.91 Pituitary fossa from above.

and middle clinoid processes of the sphenoid bone; it is perforated anteriorly by the emerging internal carotid artery, and is raised into a ridge laterally by the forward continuation of a fold of dura mater from the free edge of the tentorium cerebelli which extends to the anterior clinoid process. Just medial to this fold the third and fourth cranial nerves invaginate the roof. Medial to these nerves the roof is attached to the posterior clinoid process (Fig. 6.91). This part of the roof is continued medially as the diaphragma sellae (Fig. 6.92). Forwards of the anterior clinoid process the anterior part of the roof is the outer layer on the under surface of the lesser wing of the sphenoid (Fig. 6.93). From the ridge on the roof the inner layer of the dura mater descends to the floor of the middle cranial fossa; this sheet of dura constitutes the *lateral wall* of the cavernous sinus.

In the lateral wall (i.e. between the dura and its endothelial lining) the third and fourth cranial nerves and the ophthalmic and maxillary branches of the fifth nerve run forward. The lateral wall, meeting the floor of the middle cranial fossa, is continued laterally as the inner layer of dura across the middle cranial fossa (Fig. 6.89). The anterior limit of the lateral wall is its vertical line of fusion with the endosteum of the greater wing of the sphenoid at the lateral margin of the foramen rotundum. Further back the lateral wall is attached medial to the foramen ovale and the trigeminal (Meckel's) cave. Thus the *floor* of the sinus is a narrow strip of endosteum along the base of the greater wing of the sphenoid.

The *medial wall* of the sinus is for the most part the endosteum on the body of the sphenoid. The inner

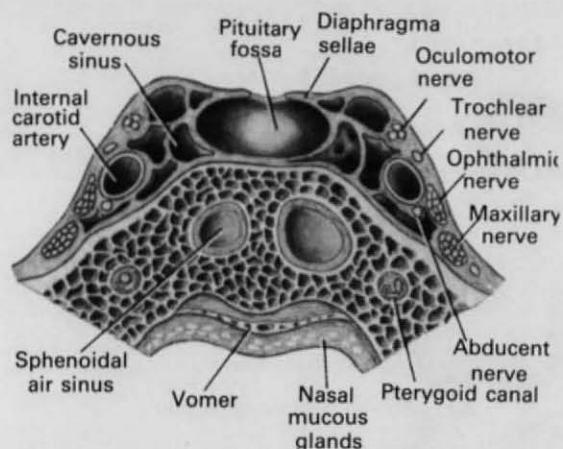


Fig. 6.92 Pituitary fossa and cavernous sinuses in coronal section.

layer of dura mater completes the medial wall alongside the pituitary fossa, so separating the sinus from the fossa (Fig. 6.92).

The inner layer of dura which covers in the posterior cranial fossa passes vertically upwards to join the roof of the cavernous sinus, thus forming a very narrow *posterior wall*. The venous blood of the sinus leaves through this posterior wall, raising the inner layer of the dura mater from the underlying periosteum of the petrous bone to form the superior and inferior petrosal sinuses (Fig. 6.94).

The *anterior wall* of the cavernous sinus is narrow, and largely taken up by the entrance through it of the ophthalmic veins from the orbit. It plugs up the medial end of the superior orbital fissure.

The cavernous sinus thus extends from the *apex* of the orbit back to the *apex* of the petrous temporal bone. Each end is pointed, so that the narrow slit-like sinus is

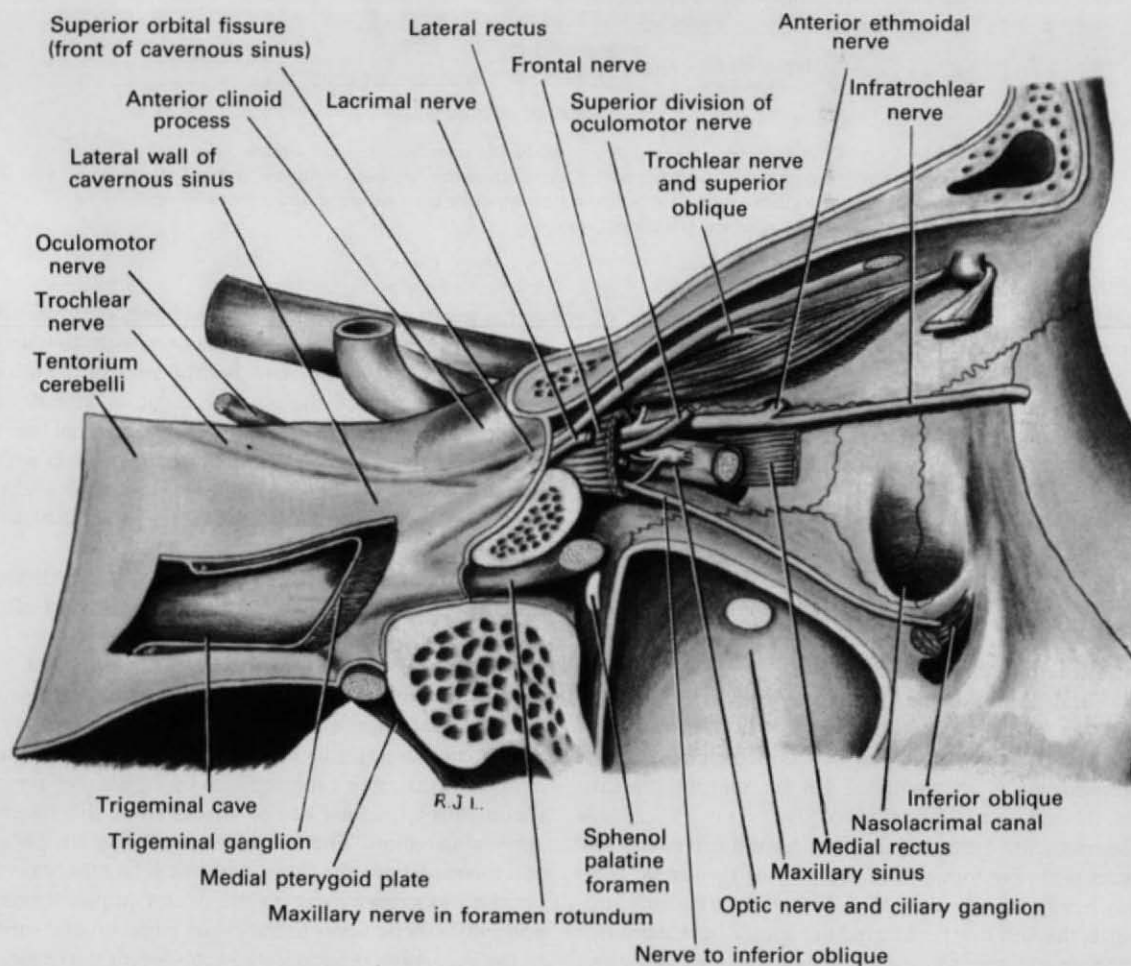


Fig. 6.93 Longitudinal section through the right orbit and middle cranial fossa, viewed from the right (lateral) side.

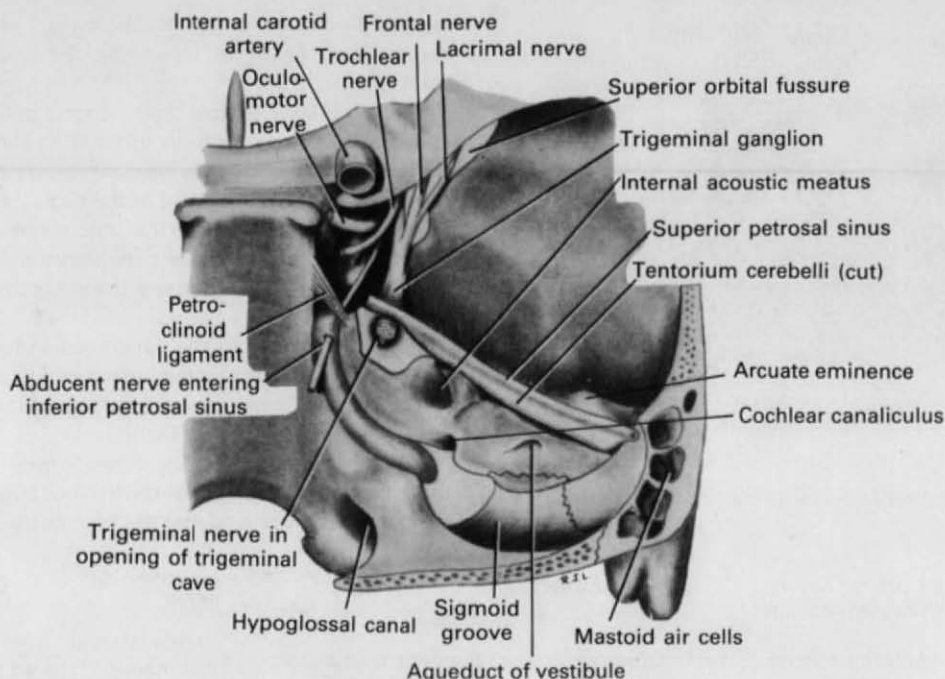


Fig. 6.94 Part of the posterior and middle cranial fossae seen from behind after sectioning the skull coronally through the mastoid process. All dura mater has been removed except for the margin of the tentorium cerebelli attached to the superior petrosal sinus and a small piece of dura around the opening of the trigeminal cave.

spindle-shaped in lateral view. The total capacity of each sinus is about 1.5 ml.

The cavernous sinus differs from all the other venous sinuses of the dura mater by being intersected with numerous septa of fibrous tissue which divide the blood space into a series of tiny caves, like the corpora cavernosa of the penis, hence the name of cavernous sinus.

Examine together a dried skull and specimen from which the brain has been removed (Fig. 6.89).

Medial to the sinus lies the body of the sphenoid bone and the fibrous lateral wall of the pituitary fossa (Fig. 6.92). The sphenoidal air sinus lies towards the front of the pituitary fossa at a lower level; its extent is very variable and tends to increase posteriorly with advancing years. *Lateral* to the sinus lies the medial surface of the temporal lobe of the hemisphere and, posteroinferiorly, in the floor of the middle cranial fossa, the trigeminal cave (Fig. 6.93).

Superiorly the emerging internal carotid artery lies in contact with the forepart of the roof of the sinus; the artery here passes backwards a little before turning up towards the anterior perforated substance of the brain. Further back and somewhat above the roof lies the uncus of the temporal lobe. *Inferiorly* the sinus rests

on the greater wing of the sphenoid bone. *Posteriorly* lies the cerebral peduncle at its junction with the upper border of the pons. *Anteriorly* lies the apex of the orbit.

The **contents** of the cavernous sinus include the structures lying within the cavity — the internal carotid artery and sixth nerve — and those embedded within the lateral wall — the third and fourth nerves and the ophthalmic and maxillary branches of the fifth nerve (Fig. 6.92).

The **internal carotid artery** curves upwards from the foramen lacerum to enter the posterior part of the sinus between the periosteum of the sphenoid bone and the inner layer of the dura. It arches upwards and then forwards, deeply grooving the medial wall of the sinus, then curves upwards to pierce the roof of the sinus just medial to the anterior clinoid process (Figs 6.91 and 6.94). The artery is accompanied by a plexus of sympathetic fibres (*internal carotid nerve*) from the superior cervical ganglion. The plexus gives off branches which run forwards into the orbit (with the long ciliary nerves via the nasociliary nerve to the dilator pupillae muscle and sympathetic fibres to the ciliary ganglion and thence to the eye, and a branch to the oculomotor nerve for the smooth muscle part of levator palpebrae superioris).

The **abducent nerve** (p. 570) enters the back of the cavernous sinus after passing over the apex of the petrous part of the temporal bone. It runs forwards on the *lateral* side of the internal carotid artery (Fig. 6.94). Further forward it lies *below* the upturning artery (Fig. 6.92), and leaves the anterior wall of the sinus to enter the superior orbital fissure (Fig. 6.20).

The **oculomotor nerve** (p. 570) enters the roof anteriorly, medial to the ridge raised up by the forward continuation of the free margin of the tentorium cerebelli (Fig. 6.89), and then passes forward in the lateral wall. It inclines downwards towards the medial end of the superior orbital fissure, and thus passes *medial* to the other nerves, namely, the trochlear nerve and the branches of the ophthalmic nerve (Fig. 6.93). At the anterior end of the sinus it breaks into its superior and inferior divisions which enter the superior orbital fissure. In its course it picks up sympathetic fibres from the internal carotid plexus; these are for the smooth muscle part of levator palpebrae superioris.

The **trochlear nerve** (see pp. 512 and 570) enters the roof of the sinus behind the oculomotor nerve, alongside the ridge of dura mater (Fig. 6.89) where the free and attached margins of the tentorium cross, and courses horizontally forwards in the lateral wall of the sinus to enter the superior orbital fissure at a higher level and lateral to the oculomotor nerve. This nerve inclines downwards medial to the trochlear as they lie in the lateral wall of the sinus.

The **trigeminal ganglion**, in its anterior part, lies forward of Meckel's cave (p. 570) (Fig. 6.89). Its **mandibular division** passes downwards to the foramen ovale and does not, strictly, come in contact with the lateral wall of the cavernous sinus. The **maxillary division** runs horizontally forwards on the medial side of the lateral wall and leaves the middle fossa through the foramen rotundum. The **ophthalmic division** divides into its three branches towards the anterior limit of the lateral wall. Two of these branches, the lacrimal and frontal, enter the orbit through the lateral part of the superior orbital fissure, the other (nasociliary nerve) slopes downwards to enter the fibrous ring at the medial end of the superior orbital fissure. All three branches are crossed medially by the downward-sloping oculomotor nerve. At the anterior end of the sinus the ophthalmic division gives off its tentorial branches to the dura mater (p. 562). In its course through the sinus the ophthalmic division picks up sympathetic fibres from the internal carotid plexus (these eventually enter the long ciliary nerves to reach the dilator pupillae muscle, p. 518).

To summarize the nerve relations: in its course through the cavernous sinus no nerve lies lateral to the

fifth and its branches, and no nerve lies medial to the sixth. The fourth runs parallel with the fifth at a higher level and the third slopes downwards crossing medial to both (Figs 6.92 and 6.93).

Veins of the cavernous sinus

Although it is customary to think of venous blood as entering the cavernous sinus at the front and leaving from behind and below, it must be remembered that blood can flow in either direction in the sinus, depending on local venous pressures. The two sinuses also communicate with each other.

The **superior ophthalmic vein** passes back directly into the anterior end of the sinus at the superior orbital fissure. The **inferior ophthalmic veins** also enter the front of the sinus, but before doing so they drain much of their blood through the inferior orbital fissure into the veins of the pterygoid plexus.

The **superficial middle cerebral vein** traverses the subarachnoid space and drains into the sinus by piercing its roof near the emerging carotid artery.

The **sphenoparietal sinus** drains blood from the skull bones over the temporal region of the vault (middle meningeal artery). It runs beneath the edge of the lesser wing of the sphenoid, lying between the two layers of the dura mater, and enters the roof of the sinus.

The **superior petrosal sinus** leaves the top of the posterior wall and, bridging the groove made by the underlying trigeminal nerve, runs back along the upper border of the petrous bone between the two layers at the attached margin of the tentorium cerebelli (Fig. 6.94). It enters the commencement of the sigmoid sinus, at the termination of the transverse sinus. It receives blood from the internal ear by several small veins that emerge from separate foramina in the petrous bone.

The **inferior petrosal sinus** is larger and empties the bulk of the blood from the cavernous sinus. It leaves the posterior wall of the sinus beneath the *petroclinoid ligament*. This is a fibrous band stretched between the apex of the petrous part of the temporal bone and the side of the dorsum sellae (Fig. 6.94). It is occasionally partly ossified. The abducent nerve lies either within or alongside the sinus *beneath* this ligament, and grooves the apex of the petrous temporal bone. The inferior petrosal sinus runs down between the two layers of the dura along the suture between the apex of the petrous bone and the side of the clivus (occipital bone). It leaves a well-marked groove on the dried skull. It enters the anterior compartment of the jugular foramen medial to the glossopharyngeal nerve and joins the

internal jugular vein a short distance below the base of the skull. It is the first (highest) tributary of this vein (p. 438 and Fig. 6.16).

The cavernous sinus drains also into the **pterygoid venous plexus** by an emissary vein which usually passes through the foramen ovale, but when the venous foramen (of Vesalius) is present it transmits a vein also. The venous foramen lies medial to the foramen ovale (Fig. 6.91).

The cavernous sinuses communicate with each other through the **intercavernous sinuses**, which form a small plexus that lies between the two layers of the dura of the pituitary fossa. A few communicating veins lie also in the diaphragma sellae.

Cavernous sinus thrombosis. The cavernous sinus is in venous connexion with the skin of part of the face whence infection may produce thrombosis. By the superficial middle cerebral vein such thrombosis can spread to the hemisphere. The 'danger area of the face' lies above the level of the deep facial vein; it comprises the upper lip and nose and medial part of the cheek. It is significant that it lies between the two veins of communication between face skin and cavernous sinus, namely, (1) the angular vein via superior ophthalmic vein directly to the cavernous sinus, and (2) deep facial vein via pterygoid plexus and the communicating veins in the foramen ovale and venous foramen.

Thrombosis of the cavernous sinus produces ophthalmoplegia from ocular nerve interruption — not dangerous — and retrograde thrombosis of the inferior petrosal sinus and medullary veins — usually fatal.

Extradural, subdural and subarachnoid haemorrhage

Fractures of the side of the skull may rupture the middle meningeal artery (especially its frontal branch) causing **extradural haemorrhage** which leads to the formation of a haematoma between the bone of the skull and the dura. The resultant swelling may cause (apart from headache) pressure on the cerebral hemisphere in the region of the motor area (p. 586), giving contralateral hemiparesis, and the medial edge of the temporal lobe may be displaced over the free edge of the tentorium, compressing the oculomotor nerve and causing dilatation of the pupil on the injured side. In severe cases the posterior cerebral artery may also be compressed, giving ischaemia of the occipital lobe including the visual area of the cortex.

Subdural haemorrhage is usually caused by rupture of a superior cerebral vein as it enters the superior sagittal sinus; the venous blood escapes into the (potential) space between the dura and arachnoid.

There may be similar pressure symptoms to those caused by extradural haemorrhage, but because venous rather than arterial blood is involved they are slower to develop and less severe.

Note that both the above types of haemorrhage do not cause blood to contaminate the cerebrospinal fluid. It is **subarachnoid haemorrhage** that does this — rupture of arteries that lie within the space, such as aneurysms of the arterial circle at the base of the brain (p. 600). Note also that none of the above types of intracranial haemorrhage ever separates the two layers of the dura, nor the pia mater from the underlying brain.

PART 22 CRANIAL FOSSAE

The bony details of the cranial fossae are described with the osteology of the skull (p. 653) and should be read before the accounts that follow here, which concentrate on the contents of the fossae.

ANTERIOR CRANIAL FOSSA

The floor of the **anterior cranial fossa** roofs in the orbits, ethmoidal sinuses and the nose. It contains the frontal lobes of the cerebral hemispheres, and the olfactory and anterior ethmoidal nerves (Fig. 6.89).

The gyri and sulci of the under surface of the frontal lobes cause grooves and ridges on the orbital parts of the floor. From the nose up to 20 **olfactory nerve** filaments (on each side) perforate the dura and arachnoid mater over the cribriform plate and pass upwards through the subarachnoid space to enter the olfactory bulb, from which the olfactory tract passes back on the inferior surface of the frontal lobe.

The **anterior ethmoidal nerve** has a very short course in the fossa. Coming in from the orbit through its foramen near the back of the cribriform plate, it runs forwards on the plate and disappears into the nasal cavity through a slit at the side of the front of the crista galli.

In only 1% of subjects is there a patent vein passing through the foramen caecum (in front of the crista galli) connecting nasal veins with the superior sagittal sinus in the falx cerebri, whose lower end is attached to the crista.

MIDDLE CRANIAL FOSSA

The **middle cranial fossa** consists of median and right

and left lateral parts. The *median part* (Fig. 6.91) contains the pituitary gland, optic nerves and chiasma, and the intercavernous sinuses. The *right and left lateral parts* each contain the cavernous sinus, the third to the sixth cranial nerves, internal carotid artery, middle meningeal vessels, and the greater and lesser petrosal nerves.

Pituitary gland

The **pituitary gland** (*hypophysis cerebri*) lies in its fossa (*sella turcica*) with the diaphragma sellae above it and the intercavernous sinuses below. On each side is a flange of dura mater separating the gland from the upper part of the cavernous sinus. Below the fossa lies the body of the sphenoid bone containing the sphenoidal air sinuses. When small the sinuses lie anteroinferior to the fossa, but when large one or both extend back beneath the fossa. The gland is in theory surrounded by the subarachnoid space, but usually the pia and arachnoid have fused together on its surface and around the pituitary stalk, lying snugly against but not fused with the dura mater of the fossa.

The **optic chiasma** lies above and towards the back of the diaphragma sellae. A pituitary tumour, rising upwards, presses on the lower anterior part of the chiasma and the medial sides of the optic nerves (so causing hemianopia of the temporal fields — p. 587). From the base of the brain the **pituitary stalk** slopes downwards and forwards to the perforation in the diaphragma, connecting the posterior part of the gland to the floor of the third ventricle (p. 594). The upper part of the stalk is hollowed out (continuous with the third ventricle) as the *infundibulum* (infundibular part of the stalk).

Structure. The gland is a composite structure consisting essentially of two main parts, the *anterior and posterior lobes*, with different developmental origins. Unfortunately these terms are not always used synonymously with *adenohypophysis* and *neurohypophysis* which indicate the developmental differences. The *adenohypophysis*, developed from the ectodermal hypopharyngeal saccule (Rathke's pouch) of the pharynx, consists of the *pars distalis*, *pars tuberalis* and *pars intermedia*, of which the *pars distalis* and *pars tuberalis* are often considered to form the anterior lobe. The *neurohypophysis*, developed as a neuroectodermal downgrowth from the floor of the third ventricle, consists of the *pars nervosa*, the infundibular stalk and the median eminence (p. 594). The *pars nervosa* and the *pars intermedia* of the *adenohypophysis* are often collectively termed the posterior lobe. However, for most purposes it is sufficient to call the *pars distalis* the

anterior lobe ('anterior pituitary') and the *pars nervosa* the posterior lobe ('posterior pituitary').

The *pars distalis* accounts for 75% of the whole gland. It is highly vascular, and its cells consist of 50% chromophobes, 35% acidophils and 15% basophils. The acidophils (eosinophils) secrete growth hormone and prolactin, with the basophils producing ACTH, TSH, FSH and LH (adrenocorticotrophic, thyroid-stimulating, follicular-stimulating and luteinizing hormones). The *pars tuberalis* is a small extension of the *pars distalis* along the pituitary stalk, but its cells are different and their function not known. The *pars tuberalis* lies in front of a narrow cleft (the remains of the pharyngeal downgrowth), behind which is the small *pars intermedia*. It consists of a number of colloid-filled vesicles and probably secretes MSH (melanocyte-stimulating hormone).

The *pars nervosa* of the neurohypophysis consists largely of about 100 000 unmyelinated nerve fibres whose cell bodies are in the supraoptic and paraventricular nuclei of the hypothalamus. Neurosecretory material manufactured in the cell bodies (mainly *oxytocin* from the paraventricular cells and *vasopressin* — antidiuretic hormone — from the supraoptic cells) migrates at the rate of about 3 mm/day along their axons which run in the pituitary stalk and end in the *pars nervosa*. Both hormones are combined with a carrier protein, *neurophysin*. Scattered among the nerve fibres are the rather scanty pituicytes which resemble astrocytes.

Blood supply and the hypophyseal portal system. Small *superior and inferior hypophyseal arteries* arise from the adjacent parts of the internal carotid and anterior and posterior cerebral arteries, and venous blood enters the adjacent cavernous and intercavernous sinuses. But in addition to these vessels there is a system of *portal venous* channels that are of fundamental importance in controlling the hormones produced by the anterior lobe. These fine vessels form a plexus on the stalk and *pars distalis*. Into them in the upper part of the stalk are secreted the various *hypophysiotropic hormones* (formerly called regulatory factors or neurohormones) derived from cells of the median eminence (p. 594) and possibly other parts of the hypothalamus. The portal vessels then transport these substances to their target cells which are the chromophils of the anterior lobe. Thus the main difference between the anterior and posterior lobes is that posterior lobe hormones are stored in the lobe within the axons of the hypothalamic neurosecretory cells that produced them, whereas anterior lobe cells are controlled by hypothalamic messengers delivered to them by a portal venous system (a very miniaturized version of the gut-to-liver

system). There is no blood/brain barrier (p. 600) in the posterior pituitary or median eminence.

Surgical approach. The gland can be approached through the anterior cranial fossa by elevating the frontal lobe of the brain, subfrontal approach, but a more common route is by the transphenoidal approach, entering the pituitary fossa from below through a sphenoidal air sinus. This is entered either via the ethmoidal air cells after raising the periosteum from the medial wall of the orbit, or by elevating the nasal mucosa from the nasal septum and removing the septum (the nasal cavity itself is not entered).

The **internal carotid artery** emerges from the roof of the cavernous sinus medial to the anterior clinoid process and curves immediately backwards, lying on the roof of the sinus before curving upwards lateral to the optic chiasma. At the anterior perforated substance it divides into its terminal branches. Of these the *anterior cerebral artery* passes forward above the optic nerve. The *anterior communicating artery*, lying in the chiasmatic cistern, lies vertically above the prechiasmatic groove between the two optic canals. The curve of the internal carotid artery in and above the cavernous sinus as seen in a lateral carotid arteriogram (like a U on its side, opening backwards) is commonly called the *carotid siphon*.

The **ophthalmic artery** branches from the internal carotid immediately above the roof of the cavernous sinus. The carotid arteries come from below and laterally, the optic nerves come from above and medially (i.e. from the chiasma), and this is the relationship of nerve and artery in the optic canal.

The **optic nerve** slopes forward, down and laterally from the chiasma to the optic canal. Clad only in pia mater, it receives its tube of arachnoid and dura mater at the optic canal. Its intracranial part, in the chiasmatic cistern, is here supplied by branches of the anterior cerebral artery that run down from the chiasma.

The **oculomotor nerve** leaves the medial side of the crus of the cerebral peduncle (Fig. 7.22, p. 604). The nerve passes forwards *between* the posterior cerebral and superior cerebellar arteries, parallel to and just below the posterior communicating artery (aneurysms may damage the nerve here). It crosses the interpeduncular cistern and enters the roof of the cavernous sinus in the middle fossa (p. 567 and Fig. 6.89), slightly indenting the dura mater thereof before running down in the lateral wall of the sinus. The parasympathetic preganglionic fibres for the pupil (from the Edinger-Westphal nucleus) are on the outer part of the nerve (first dorsal, then medial and then inferior as it enters the sinus); external pressure (as from an aneurysm of the posterior

communicating artery) may damage these fibres, but arteriosclerotic infarction of the nerve trunk (as in diabetes) may spare them.

The **trochlear nerve**, after emerging from the dorsal surface of the brainstem behind the inferior colliculus (p. 606), curls around the cerebral peduncle below the posterior cerebral artery and runs forward above the superior cerebellar artery, lateral to the oculomotor nerve in the interpeduncular cistern, just below the free margin of the tentorium cerebelli (i.e. in the posterior fossa). It enters the middle fossa just behind the oculomotor nerve and pierces the dura mater at the back of the roof of the cavernous sinus (Fig. 6.89) where the free and attached margins of the tentorium cerebelli cross each other.

The **abducent nerve** leaves the posterior cranial fossa (p. 571) by passing over the apex of the petrous temporal and then runs round the lateral side of the ascending part of the internal carotid artery (Fig. 6.94) to enter the cavernous sinus.

The **posterior communicating artery**, joining the internal carotid and posterior cerebral artery in the circle of Willis, lies in the interpeduncular cistern, above and lateral to the pituitary gland (Fig. 7.23, p. 605).

Trigeminal ganglion

The **trigeminal ganglion** lies beneath the dura mater in the floor of the middle cranial fossa alongside the cavernous sinus, and occupies the *trigeminal impression* on the front of the apex of the petrous temporal bone. The trigeminal nerve leaves the pons in the posterior fossa and runs forwards to cross the upper border of the petrous bone, upon which it leaves a shallow groove some 5 mm wide. It passes *beneath* the superior petrosal sinus at this point (Fig. 6.94). The posterior half of the ganglion lies in a diverticulum of dura and arachnoid, the **trigeminal cave** (of Meckel), where it indents the petrous bone alongside the foramen lacerum, so forming the trigeminal impression. Here the *greater petrosal nerve* lies beneath the cave, between the two layers of the dura mater. The anterior half of the ganglion lies, in its upper part, in the dura mater of the lateral wall of the cavernous sinus. The inner layer of dura joining the superior petrosal sinus to the petrous bone is evaginated around the sensory and motor roots of the trigeminal nerve and does not fuse with the pia mater until as far forwards as the middle of the trigeminal ganglion (Fig. 6.93). As elsewhere, the evagination of dura mater supports the contiguous arachnoid, so that sensory and motor roots of the nerve *and the posterior half of the ganglion* are bathed in cerebrospinal fluid.

This fluid space, surrounding the nerve and posterior half of the ganglion, is the trigeminal cave. It lies in the middle cranial fossa, but its *mouth* opens backwards into the *posterior* fossa. The dura mater forming the walls of the cave is evaginated between the two layers of dura which elsewhere clothe the floor of the middle fossa. Thus above the cave lie two inner layers of dura fused and continuous with each other posteriorly around the superior petrosal sinus and tentorium, while below the cave lies the inner layer fused to the outer layer of the dura mater (Figs 6.93 and 6.94).

Blood supply. Ganglionic branches leave the internal carotid artery in the cavernous sinus and these are usually stated to be the blood supply to the ganglion. But a very appreciable amount of blood is brought to the ganglion by the accessory meningeal artery which enters the foramen ovale and runs up along the mandibular division to reach the ganglion, a similar arrangement to that in the spinal nerves.

Nerve supply. The epineurium of the ganglion and the adjacent dura mater are supplied by the meningeal branch of the mandibular nerve (nervus spinosus).

Surgical approach. The sensory root and posterior half of the ganglion, bathed in the cerebrospinal fluid in Meckel's cave, can be approached only across the subarachnoid space. The anterior half of the ganglion and the three divisions of the trigeminal nerve lie in front of Meckel's cave. The *upper* part of the ganglion, with the ophthalmic and maxillary divisions, here lies in the fibrous lateral wall of the cavernous sinus. The *lower* part of the ganglion and the mandibular division lie in the middle fossa fused between the two layers of dura mater. Extradural approach is therefore possible across the floor of the middle fossa by stripping the dura from the bone, avoiding entry into the subarachnoid space.

Transient *facial* palsy sometimes follows the latter approach. The explanation is thought to be that in stripping up the dura from the floor of the middle fossa tension is exerted on the greater petrosal nerve and therefore on the geniculate ganglion. Subsequent oedema here causes pressure on the motor fibres of the facial nerve with paralysis of the muscles until the oedema subsides and the nerve recovers.

The **mandibular division** of the trigeminal nerve passes laterally to descend through the foramen ovale (Fig. 6.89), so that it never comes into contact with the lateral wall of the cavernous sinus. It is joined in the foramen ovale by the small *motor root* to emerge as the (mixed) mandibular nerve, a similar arrangement to that of the spinal nerves in the intervertebral foramina.

The **maxillary nerve** passes forwards within the

inner layer to leave the skull through the foramen rotundum (Fig. 6.89). The branches of the **ophthalmic nerve** pass forwards likewise, to leave the skull through the medial end of the superior orbital fissure. The *superior orbital fissure* is elsewhere plugged by the inner layer of dura mater which passes across between the edges of the greater and lesser wings of the sphenoid bone.

The **greater petrosal nerve** (from the nervus intermedius part of the facial, p. 530) emerges from its hiatus in the petrous bone (Fig. 8.8, p. 658) and runs obliquely forwards, between the two layers of the dura mater and beneath the trigeminal ganglion to the foramen lacerum. Here it is joined by the **deep petrosal nerve**, a branch from the carotid plexus of sympathetic nerves. The two join to form the **nerve of the pterygoid canal** (Vidian nerve). This nerve enters the posterior end of the pterygoid canal in the foramen lacerum and runs along the canal to join the pterygopalatine ganglion (p. 468).

The **lesser petrosal nerve** (from the glossopharyngeal, p. 530) leaves its hiatus in the petrous bone (Fig. 8.8, p. 658) and runs forwards beneath the fibrous floor of the middle cranial fossa to emerge through the foramen ovale (or petrosal foramen, p. 651) to join the otic ganglion (p. 462).

The middle meningeal artery is considered on page 562.

POSTERIOR CRANIAL FOSSA

The **posterior cranial fossa** lodges the convexities of the cerebellar hemispheres as well as the pons and medulla oblongata. In it the fifth to twelfth cranial nerves inclusive pierce the dura mater (Fig. 6.96).

The **trigeminal nerve** leaves the anterolateral surface of the pons by two roots, a *large sensory* and a *small motor* (Fig. 7.22, p. 604). They lie close together. The motor root emerges somewhat above and medial to the sensory root, but spirals to enter the mouth of Meckel's cave below it. The sensory root itself shows a spiral arrangement of its fibres. At the junction with the pons the mandibular fibres lie superior, the ophthalmic inferior with the maxillary fibres between, but in Meckel's cave the mandibular fibres lie most laterally and the ophthalmic fibres most medially.

The **abducent nerve** leaves the brainstem near the ventral midline at the junction of the pons and the pyramid of the medulla (Fig. 7.22, p. 604) and runs upwards through the pontine cistern. It evaginates the dura mater of the clivus some distance above its origin from the brainstem, and runs thence upwards between the two layers of the dura to enter the inferior petrosal

sinus, in which it passes over the groove at the apex of the petrous bone. It thereby enters the posterior end of the cavernous sinus. The relatively long intracranial course of this delicate nerve renders it particularly vulnerable to increase of intracranial pressure; paralysis of the lateral rectus is often an early sign in such cases.

The **facial** and **vestibulocochlear nerves**, with the intervening **nervus intermedius** part of the facial nerve, leave the junction of pons and medulla (Fig. 7.22, p. 604) and pass laterally and somewhat upwards to enter the internal acoustic meatus. The *labyrinthine artery* lies with them. This vessel is usually a branch of the basilar artery, but it often arises from the anterior inferior cerebellar artery.

The **internal acoustic meatus** is a foramen directed laterally in the posterior surface of the obliquely set petrous bone. Its fundus consists of a plate of bone, the **lamina cribrosa**, divided by a horizontal crest into an upper and lower semicircle (Fig. 6.95). The inner layer of the dura mater is everywhere fused with the endosteum within the meatus.

If it is remembered that in the petrous bone the cochlea lies *in front of* the vestibule and that the facial nerve passes in its bony canal *above* the vestibule, the arrangement of the structures in the meatus will become clear. Thus the facial nerve and its nervus intermedius part pierce the front of the *upper* part, the cochlear nerve the front of the *lower* part (by many branches in spiral arrangement). The vestibular nerve pierces the plate posteriorly, by upper and lower divisions that lie behind the facial nerve foramen, and the spiral cochlear foramina respectively. Each division of the vestibular nerve has a ganglion deep in the meatus. Behind the vestibular area is a single foramen

(the *foramen singulare*) for the passage of the nerve to the posterior semicircular duct. The labyrinthine artery divides in the meatus and its branches accompany the nerves through the bony plate.

The **subarcuate fossa** lies lateral to the internal acoustic meatus, below the arcuate eminence (Fig. 6.89). It is a very shallow fossa against which the flocculus of the cerebellum lies; in the neonatal skull this fossa is as large and as deep as the internal acoustic meatus and it lodges the flocculus.

Further laterally on the posterior surface of the petrous bone is the orifice of the **aqueduct of the vestibule**, a narrow slit overhung by a sharp scale of bone. The endolymphatic sac hangs down from this slit beneath the inner layer of the dura (Fig. 6.94).

The **glossopharyngeal, vagus and accessory nerves** arise from the side of the medulla oblongata as a series of rootlets lying vertically between the olive and the inferior cerebellar peduncle (Fig. 7.22, p. 604). The three nerves pass laterally across the occipital bone in that order, behind the jugular tubercle. All three pass through the jugular foramen (Fig. 6.96).

The **spinal root of the accessory nerve** is seen entering the posterior fossa through the foramen magnum (Fig. 6.96). It arises by a series of rootlets that emerge from the lateral surface of the upper five or six segments of the cervical cord *posterior* to the denticulate ligament. These rootlets unite into a single trunk that passes forwards over the top of the ligament lateral to the vertebral artery. It unites with the cranial root medial to the jugular foramen.

The **jugular foramen** is divided by two transverse septa of the inner layer of dura into three compartments. These septa may ossify. The glossopharyngeal nerve and inferior petrosal sinus share the anterior compartment, vagus and accessory nerves lie in the middle compartment, while the large posterior compartment is occupied by the termination of the sigmoid sinus. Examine the jugular foramen in the dried skull. The inferior border of the petrous bone shows a deep notch immediately below the internal acoustic meatus. This notch, the cochlear canaliculus, (Fig. 6.94) is indented by the glossopharyngeal nerve; the aqueduct of the cochlea (p. 532) opens into the depths of the notch and by this means perilymph drains into the subarachnoid space (the arachnoid making a tubular projection into the opening of the aqueduct). The groove made by the inferior petrosal sinus will be seen to enter the jugular foramen medial to the notch.

In the central compartment of the jugular foramen the accessory nerve descends lateral to the vagus. It is worth noting the arrangement of the nerves as they pass

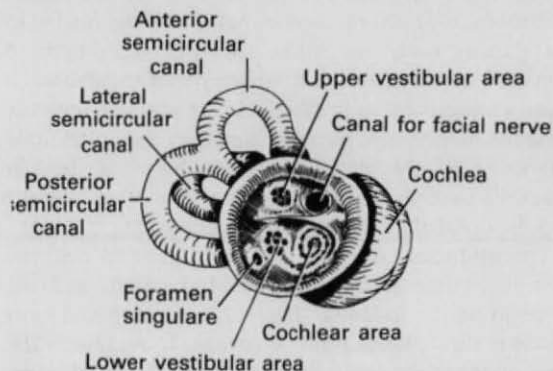


Fig. 6.95 Left internal acoustic meatus with the osseous labyrinth.

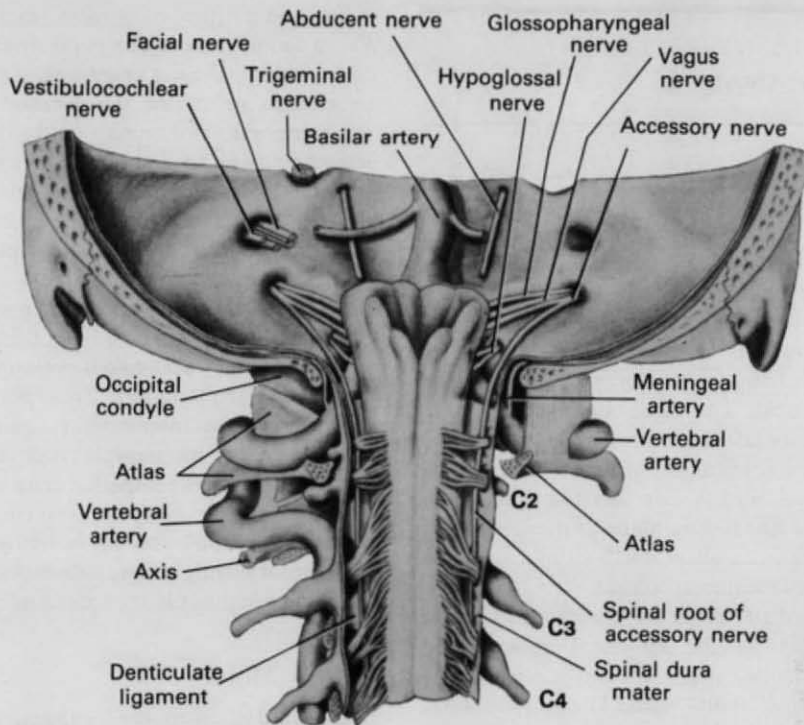


Fig. 6.96 Posterior cranial fossa and the vertebral canal opened from behind.

down through the jugular foramen, since it explains their relationship at the base of the skull between the carotid sheath and the deep part of the parotid gland (p. 462). The essential point is that the glossopharyngeal and accessory nerves lie more laterally than the vagus in the foramen.

The **hypoglossal nerve** leaves the medulla by a vertical series of rootlets between the pyramid and the olive (Fig. 7.22, p. 604). The rootlets unite into two roots which enter the hypoglossal canal separately, divided from each other by a septum of dura mater which occasionally ossifies. The hypoglossal canal lies in the epiphyseal junction between the basiocciput and the jugular process of the occipital bone (Fig. 8.9, p. 659).

The **arteries** in the posterior fossa comprise the two vertebral and the basilar arteries with their branches. Before piercing the spinal dura mater, but after piercing the posterior atlanto-occipital membrane the vertebral arteries give off meningeal branches which enter the posterior fossa between the two layers of the dura mater at the foramen magnum (Figs 6.90 and 6.96).

The **vertebral artery** then pierces the spinal dura mater and arachnoid, gives off two small *posterior spinal*

arteries, and runs forward in front of the denticulate ligament between the lower rootlets of the hypoglossal nerve and the upper rootlets of the first cervical nerve. It gives off the *anterior spinal artery* and the *posterior inferior cerebellar artery* and spirals up to meet its opposite fellow at the lower border of the pons to form the *basilar artery*. The posterior and anterior spinal arteries pass downwards through the foramen magnum on the spinal cord (p. 626). The posterior inferior cerebellar artery is perhaps the most tortuous artery in the body. Its coils insinuate themselves between the rootlets of the hypoglossal, accessory and vagus nerves and the vessel is distributed to the cerebellum and medulla (p. 611).

The **basilar artery** runs up in front of the pons. It is not responsible for the ventral median groove in the pons; indeed, the artery is usually curved to one side of the midline (Fig. 6.96). It gives off the *anterior inferior cerebellar artery* and many *pontine branches*. The *labyrinthine artery* arises from the anterior inferior cerebellar or directly from the basilar trunk. The basilar artery ends at the upper border of the pons by dividing into the **posterior cerebral arteries** (p. 601), immediately after giving off the *superior cerebellar branches*.

PART 23

VERTEBRAL CANAL

The **vertebral canal** (spinal canal) (p. 540) is a smooth-walled tubular space formed by the whole series of vertebral foramina lying one above the other (p. 536). Its anterior boundaries are the bodies of the vertebrae, intervertebral discs and the posterior longitudinal ligament. Posteriorly are the vertebral laminae and ligamenta flava, while at the sides are the pedicles of the vertebrae and the large intervening spaces, the intervertebral foramina. The canal contains the spinal meninges and the spinal cord with its nerve roots. Its lower end becomes continuous with the sacral canal (p. 554). The spinal cord is narrower than the spinal dura mater and the spinal dura mater is narrower than the canal. Thus each can adapt itself without strain to the movements of the vertebral column.

The bony walls of the canal are separated from the contained meninges by the **epidural space** (also known as the **extradural space** — the terms are synonymous) which contains fat and veins. The extradural fat extends laterally into the intervertebral foramina with the nerve roots within their dural sheaths. The veins form the **internal vertebral venous plexus** (Fig. 6.97). The plexus receives its tributaries mostly from the large **basivertebral veins** draining the active red marrow in the bodies of the vertebrae (p. 543). The plexus is largely

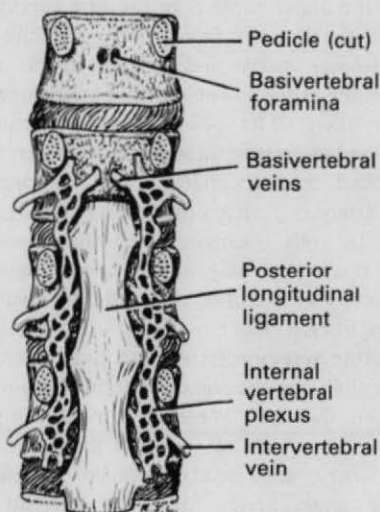


Fig. 6.97 Internal vertebral venous plexus. The basivertebral veins emerge from beneath the posterior longitudinal ligament and enter the plexus, which drains by intervertebral veins into the local segmental veins.

a longitudinal line of veins on each side of the canal, like a ladder whose rungs are made by each pair of basivertebral veins. The internal vertebral plexus sends its efferent veins (the *intervertebral veins*) through the intervertebral foramina and between adjacent ligamenta flava to drain into the segmental veins. The basivertebral veins might have drained independently through their intervertebral foramina, without linking into this longitudinal extradural plexus. The internal vertebral plexus exists as a bypass of the diaphragm. It functions when the inferior vena cava cannot cope with a sudden flush of blood resulting from a sudden increase of intra-abdominal pressure (e.g. in coughing or abdominal straining). Thus pelvic and abdominal venous blood is momentarily squirted up the plexus into posterior intercostal veins and so above the diaphragm into the superior vena cava. There are no valves in these veins, and so communication exists between the bodies of the vertebrae and, particularly, the thyroid gland, breast, kidney and prostate (p. 543), significant perhaps in the spread of cancer.

SPINAL MENINGES

The **spinal dura mater**, or **theca**, is a prolongation of the inner layer of the dura mater of the posterior cranial fossa. It extends downwards through the foramen magnum to the level of S2 vertebra. It is attached rather firmly to the tectorial membrane and to the posterior longitudinal ligament on the body of the axis vertebra, but elsewhere in the spinal canal it lies free of bony or ligamentous attachments. It is separated from the spinal canal by a layer of fat in which lies the internal vertebral venous plexus. The spinal dura is pierced segmentally by the anterior and posterior roots of the spinal nerves and is prolonged over these roots to form a series of lateral projections, one entering each intervertebral foramen. Thus the loose-fitting theca is stabilized within the spinal canal.

The **spinal arachnoid mater** is supported by the inner surface of the spinal dura; nothing but a thin film of lymph separates these two membranes. The arrangement is similar to that in the skull. Below the level of the spinal cord (i.e. over the cauda equina) the arachnoid is nothing but a delicate membrane that is supported by the dura mater, but over the spinal cord itself the spinal arachnoid sends many delicate web-like processes across the subarachnoid space to the pia mater on the cord. They are rather well developed in the posterior midline, where they form an incomplete *posterior median septum*.

The **spinal pia mater**, as in the cranium, invests the surface of the central nervous system. It clothes the

spinal cord and enters to line the anterior median sulcus. It is prolonged over the spinal nerve roots and blends with their epineurium. It is projected below the apex of the conus medullaris, whence it extends as the **filum terminale** to perforate the spinal theca at the level of S2 vertebra. It then descends to the back of the coccyx (Fig. 6.82). The filum terminale lies centrally in the cauda equina, but is not classified as part of the cauda which consists of nerve roots only (p. 620). A lateral projection of pia mater on each side forms the **denticulate ligament**. This forms a flange which crosses the subarachnoid space and, piercing the arachnoid, connects the side of the spinal cord to the dura mater. It is attached in an unbroken line along the spinal cord from the foramen magnum to the conus medullaris, but its lateral edge is connected to the spinal dura by a series of 'teeth', which are attached to the spaces between the issuing nerve roots. The root of L1 lies at the lowest denticulation. The denticulate ligament, filum terminale and the attached nerve roots serve to stabilize the loose-fitting spinal cord within the spinal dura mater (Fig. 6.98).

The **spinal subarachnoid space** is relatively large, accommodating about half of the total volume of cerebrospinal fluid (75 ml out of 150 ml). It communicates through the foramen magnum with the subarachnoid space of the posterior cranial fossa. Some cerebrospinal fluid percolates away along the meningeal sheaths of the spinal nerves.

Below the level of the conus medullaris it contains only the cauda equina and filum terminale, and it ends at the level of S2 vertebra.

Lumbar puncture and spinal and epidural anaesthesia

In **lumbar puncture** the needle is inserted between the spines of L3 and L4 or L4 and L5 vertebrae when the patient's back is flexed, usually when curled up lying on one side. The needle passes through the supraspinous and interspinous ligaments and through or between ligamenta flava before reaching the dura which is penetrated with a characteristic 'give'. Since the spinal cord ends at the level of L1 vertebra, it is in no danger.

In **spinal anaesthesia**, the anaesthetic solution is injected into the subarachnoid space (with the needle in

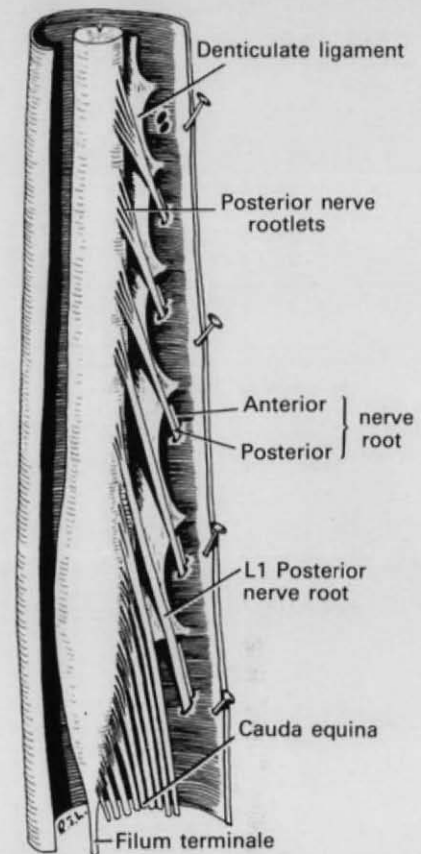


Fig. 6.98 Lower end of the spinal cord exposed by opening the dura and arachnoid mater. On the left the nerve roots and denticulate ligament have been removed.

a similar position to that used for lumbar puncture), so mixing with the cerebrospinal fluid surrounding the nerve roots and percolating into them.

In **epidural anaesthesia** (commonly used in childbirth), the solution is injected into the epidural (extradural) space without penetrating as far as the dura, so that the solution can infiltrate through the meningeal sheaths containing the lumbar and sacral nerve roots. The approach is similar to that for lumbar puncture, but formerly (though less common now) an alternative approach was into the sacral canal through the sacral hiatus.

7. Central nervous system

General plan

The **central nervous system** consists of the **brain** and **spinal cord** (spinal medulla). Developmentally the brain consists of the forebrain, midbrain and hindbrain. The *forebrain* is composed of the cerebrum (the two cerebral hemispheres, each with a cavity, the lateral ventricle), and a deeper central portion, the diencephalon, whose main parts are the thalamus and hypothalamus and whose cavity is the third ventricle. Despite this academic distinction between parts, each half of the forebrain is commonly called simply the cerebral hemisphere. The *midbrain* is a small region whose cavity is the aqueduct and which connects the forebrain with the *hindbrain*, consisting of the pons, medulla oblongata and cerebellum and whose cavity is the fourth ventricle. The midbrain, pons and medulla collectively form the brainstem. All parts of the brain are contained within the cranial cavity; the medulla passes through the foramen magnum of the skull and changes its name to spinal cord where the first cervical nerve roots emerge. Cerebrospinal fluid is produced by the choroid plexuses within parts of the ventricles; its only exit is through foramina in the roof of the fourth ventricle, in the medulla.

PART 1 CEREBRAL HEMISPHERES

The **cerebral hemispheres** occupy the greater part of the cranial cavity — above the floors of the anterior and middle cranial fossae, and above the tentorium cerebelli. One hemisphere, usually the left in right-handed people, is slightly larger than the other and constitutes the *dominant hemisphere*. The medial surface of each hemisphere is flat and lies against the falx cerebri; below the falx the two hemispheres are joined by the corpus callosum. The under surface of the hemisphere is more irregular than the medial surface;

the orbital surface of the frontal lobe is slightly concave from the impression of the anterior cranial fossa, the temporal pole is boldly convex in conformity with the middle cranial fossa while the under surface of the occipital lobe slopes downwards and outwards to conform with the shape of the tentorium. The under surfaces of the two hemispheres are joined by the cerebral peduncles of the midbrain; anteriorly lie the structures of the under surface of the diencephalon (Fig. 7.22). The lateral surfaces of the hemispheres are boldly convex in conformity with the shape of the skull; the more complete term 'superolateral' is usually applied to this convex surface.

All surfaces of the cerebral hemisphere are covered with a **cortex** of grey matter (the cells of the cerebral cortex), and internally there are further groups of cells that form such structures as the basal nuclei and thalamus. The cortex is thrown into a complicated series of tortuous folds, the *gyri*; the grooves between them are the *sulci* (Fig. 7.1). All the gyri and sulci are named but only the most important are here described. Although the patterns of no two brains are identical, there is always an underlying similarity and this general pattern common to all must be appreciated.

Some of the larger sulci are used to divide the surface of the hemisphere into **lobes** which are named according to the cranial bones that lie adjacent when the brain is in situ: frontal, temporal, parietal and occipital lobes. Further details are given below but the essential features can be summarized by stating that the **frontal lobe** lies in front of the central sulcus and above the lateral sulcus; the **parietal lobe** is behind the central sulcus and above the lateral sulcus; the **temporal lobe** is below the lateral sulcus; and the **occipital lobe** lies below and behind the parieto-occipital sulcus.

SURFACE FEATURES

Superolateral surface

A deep fissure that separates the frontal and temporal

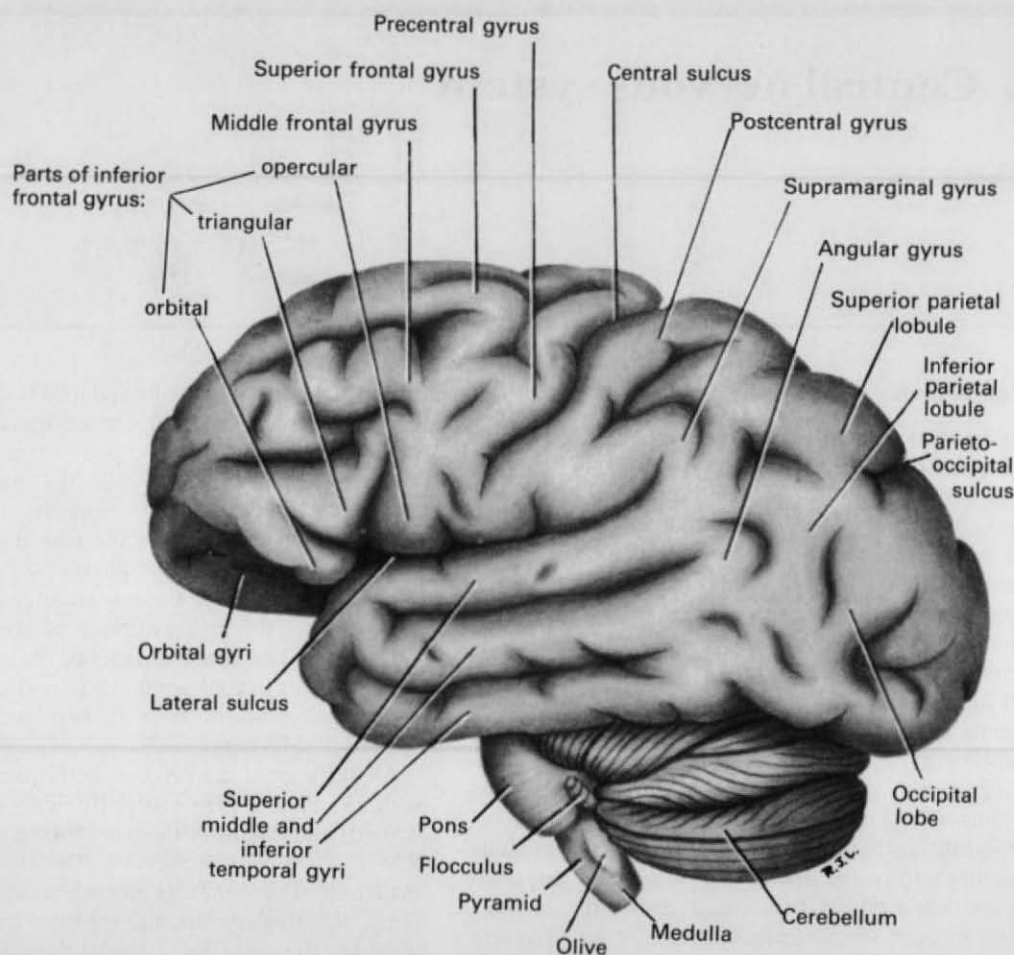


Fig. 7.1 Left side of the brain, with the gyri somewhat simplified.

lobes on the under surface of the brain is continued to the lateral surface and passes backwards, above the temporal lobe. This is the **lateral sulcus** (fissure of Sylvius) (Fig. 7.1), although strictly speaking the part on the lateral surface is the *posterior ramus* of the lateral sulcus, for, at the front end of this part, there are short *anterior* and *ascending rami* that branch off from it to penetrate the inferior frontal gyrus. The areas of cortex bounding the short sulci are the orbital, triangular and opercular parts of the *inferior frontal gyrus*, and they have to be noted because on the left hemisphere this is the region of the *motor speech area* (of Broca, p. 586). The triangular part with the adjacent areas of parietal and temporal cortex form the *opercula* which overlie a buried part of the cortex, the *insula* (Fig. 7.2), composed of various *long* and *short gyri* almost completely surrounded by the *circular sulcus*.

An oblique sulcus passes up from just behind the

opercula to indent the superior border of the hemisphere *just behind the midpoint*. It is the *only long sulcus to pass over on to the medial surface* of the hemisphere. This is the **central sulcus** (fissure of Rolando) and it separates frontal and parietal lobes (Fig. 7.1). The **precentral** and **postcentral gyri** lie in front of and behind it; they contain the motor and sensory cortical areas. In front of the precentral gyrus the **frontal lobe** is divided by two horizontal sulci into three gyri, the superior, middle and inferior *frontal gyri*. A similar arrangement divides the temporal lobe below the lateral sulcus into superior, middle and inferior *temporal gyri*. Note that the central sulcus does not usually run directly into the lateral sulcus — a useful point when identifying the central sulcus.

The **parietal lobe** is divided by a transverse sulcus into superior and inferior parietal lobules. Into the latter project the lateral sulcus and the superior

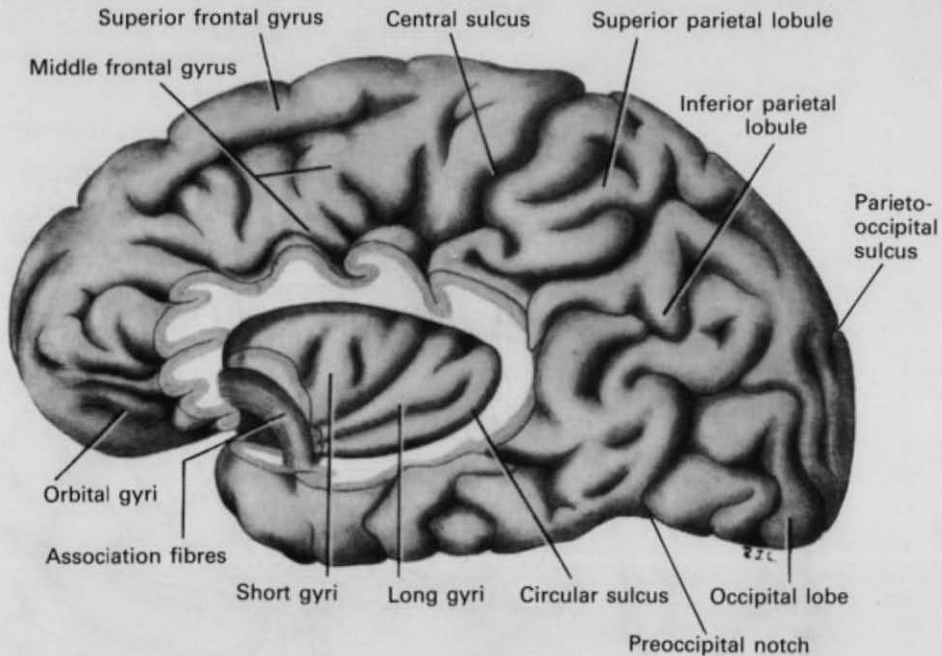


Fig. 7.2 Left cerebral hemisphere with the insula exposed by removal of the opercula.

temporal sulcus; the posterior ends of these sulci are closed by the curved *supramarginal* and *angular gyri* respectively.

An imaginary line divides the **occipital lobe** from the parietal and temporal lobes. It extends from the small part of the parieto-occipital sulcus visible on this lateral surface, downwards in a 45° slope to the inferior border where there is often a slight *preoccipital notch* (Fig. 7.2) indented in the border by a fold of dura mater over the transverse sinus. A further arbitrary line, carried backwards from the main direction of the lateral sulcus until it meets the occipital demarcation line, indicates where the parietal and temporal lobes join.

Medial surface

The two medial surfaces are flat and lie close together; they can be inspected only when their midline connexions are divided by sagittal section (Fig. 7.3). Such a section severs the **corpus callosum** and the roof and floor of the third ventricle, as well as the brainstem and cerebellum if these are still attached to the cerebral hemispheres. The wall of the **third ventricle** thus exposed beneath the corpus callosum is described on page 593. The medial surface of the hemisphere above the corpus callosum forms the *cingulate gyrus*, above which is the *cingulate sulcus*. Above the sulcus the *medial frontal gyrus* extends, anteriorly, to the superior border

of the hemisphere. Just behind the midpoint of the superior border the central sulcus turns on to the medial surface; it is enclosed in the paracentral lobule.

At the posterior end of the hemisphere, the oblique *parieto-occipital sulcus* separates the parietal from the occipital lobe; it extends over the superior border to appear, as previously noted, on the superolateral surface. The medial surface of the occipital lobe is wedge-shaped and is named the *cuneus*. Between the parieto-occipital sulcus and the paracentral lobule is the *precuneus*.

The *cuneus* is limited inferiorly by the **calcarine sulcus** which runs forward from the occipital pole to the medial surface of the temporal lobe. The sulcus is of great importance because of the associated visual area of the *cortex* (p. 586). The parieto-occipital sulcus runs into it. In old terminology the part of the calcarine sulcus below the *cuneus* was called the *posterior calcarine sulcus*. Note that the parieto-occipital and calcarine sulci form an easily identifiable pattern like the letter Y on its side; the common stem of the Y is the anterior part of the calcarine sulcus, and the two limbs are the parieto-occipital sulcus and the posterior part of the calcarine sulcus.

The *lingual gyrus* lies below the posterior part of the calcarine sulcus and is limited at the border between the medial and inferior surfaces of the occipital lobe by the collateral sulcus (see below).

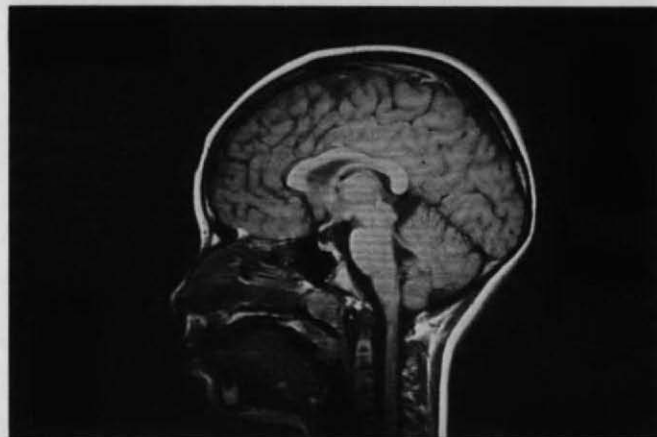
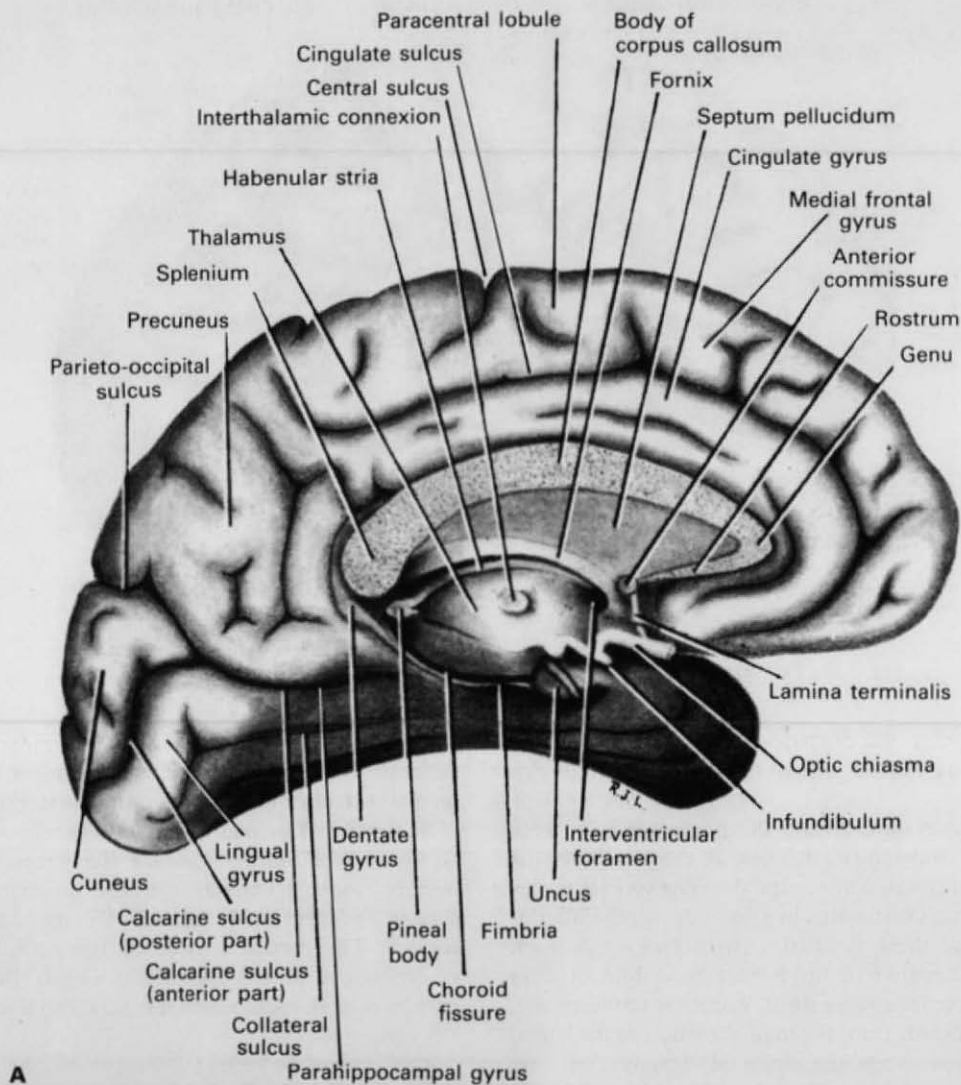


Fig. 7.3 Brain and brainstem in sagittal section. **A** The medial surface of the left cerebral hemisphere, with the cerebellum and brainstem removed to expose the choroid fissure and the under surface of the hemisphere. **B** MR (magnetic resonance) image of the head. Compare with **A** and note the corpus callosum, fornix, thalamus and interventricular foramen. The triangular fourth ventricle is seen between the cerebellum and brainstem.

The medial surface of the temporal lobe can be seen fully only when the cerebral peduncles are divided and the brainstem removed. It is best studied with the choroid fissure (p. 597).

The parts on the medial surface immediately surrounding the corpus callosum and diencephalon belong to the limbic system, discussed on page 588.

Inferior surface

This shows the orbital surfaces of the frontal lobes and the sloping inferior surface of the temporo-occipital part of the brain (Fig. 7.4).

The orbital surface of the frontal lobe has the straight *gyrus rectus* along its medial margin. Lying on the *gyrus rectus* is the **olfactory bulb**. The **olfactory tract** runs in the olfactory sulcus alongside the *gyrus rectus*. Lateral to the olfactory bulb and tract this surface is gently concave and is divided into a series of orbital gyri and sulci which leave prominent impressions on the orbital part of the frontal bone.

The temporal pole is boldly convex; the temporal lobe merges posteriorly with the occipital lobe and the continuous surface so formed is concave and oblique in conformity with the slope of the tentorium cerebelli, against which it lies. Hence much of the medial surface of the temporal lobe can be seen from the inferior view; the tentorial surface under review is really inferomedial on the hemisphere. It is characterized by two long parallel sulci, the *occipitotemporal sulcus* laterally and the *collateral sulcus* medially (Fig. 7.3A). They run antero-posteriorly between the temporal and occipital poles. Medial to the collateral sulcus is the *parahippocampal gyrus*, confined to the temporal lobe and recurved anteriorly to form the *uncus* (Fig. 7.3A); at the back it may appear to become continuous with the front of the lingual gyrus.

Between the temporal poles the midline structures inferior to the floor of the third ventricle can be seen. They lie in front of the cerebral peduncles of the midbrain and are bounded in front by the **optic chiasma**. From the chiasma the **optic tracts** diverge around the cerebral peduncles, high up under cover of the temporal lobe. Behind the chiasma lies a rounded elevation, the **tuber cinereum**, from which the **pituitary stalk** projects downwards in the intact brain. Behind the tuber cinereum are the rounded eminences of the **mamillary bodies** and, behind these, deep in the angle between the cerebral peduncles, the **posterior perforated substance** (Fig. 7.4).

On the inferior surface of the frontal lobe immediately lateral to the chiasma is the **anterior perforated substance**; the medial and lateral divisions of the olfac-

tory tract can be seen diverging around this area (Fig. 7.4).

INTERNAL STRUCTURE

The interior of the cerebrum is characterized by the presence within the white matter of large masses of **grey matter** and also by cavities which contain the cerebrospinal fluid. The largest mass of cells in each hemisphere is the *thalamus*. It belongs to the diencephalon, the central part of the forebrain, and is described on page 595.

Other cell groups belong to the lateral part of the forebrain and some of them constitute the **basal nuclei** (still commonly called by their old name, **basal ganglia**). They are usually classified anatomically as consisting of the caudate nucleus, lentiform nucleus (which has an outer part, the putamen, and an inner part, the globus pallidus), the amygdaloid body and the claustrum. Unfortunately there is no agreement on what should be included among the basal nuclei; the amygdaloid body is often excluded and placed among the components of the limbic system because of its association with memory and behaviour, while the substantia nigra and subthalamic nucleus (although mainly in the midbrain rather than the cerebrum) are often included because of their profuse connexions with the lentiform nucleus. However, among these uncertainties there are two highly important and universally recognized facts: (1) the caudate nucleus and the putamen part of the lentiform nucleus are joined by many interconnecting fibres to form what is collectively known as the **corpus striatum** (from the striated naked-eye appearance), and (2) fibres from the *globus pallidus* part of the lentiform nucleus form the *main efferent pathway* from the corpus striatum.

The **caudate nucleus** has the shape of a highly curved comma (Figs 7.5 and 7.6) with a head, body and tail. The bulbous *head* tapers back to the *body* which, curving back round the lateral part of the thalamus, bends sharply forwards into the long thin *tail* that joins the amygdaloid body. The caudate nucleus is curled snugly round the internal capsule like a hand holding a bunch of flowers. The whole length of its convexity projects into the lateral ventricle.

The **lentiform nucleus** is the shape of a biconvex lens, completely buried in the hemisphere (Figs 7.6 and 7.7). It is oval in outline and has two parts: the large lateral **putamen**, curved and roughly quadrilateral in shape, and the small medial **globus pallidus**, bluntly conical. The putamen is joined to the head of the caudate nucleus by bundles of myelinated and unmyeli-

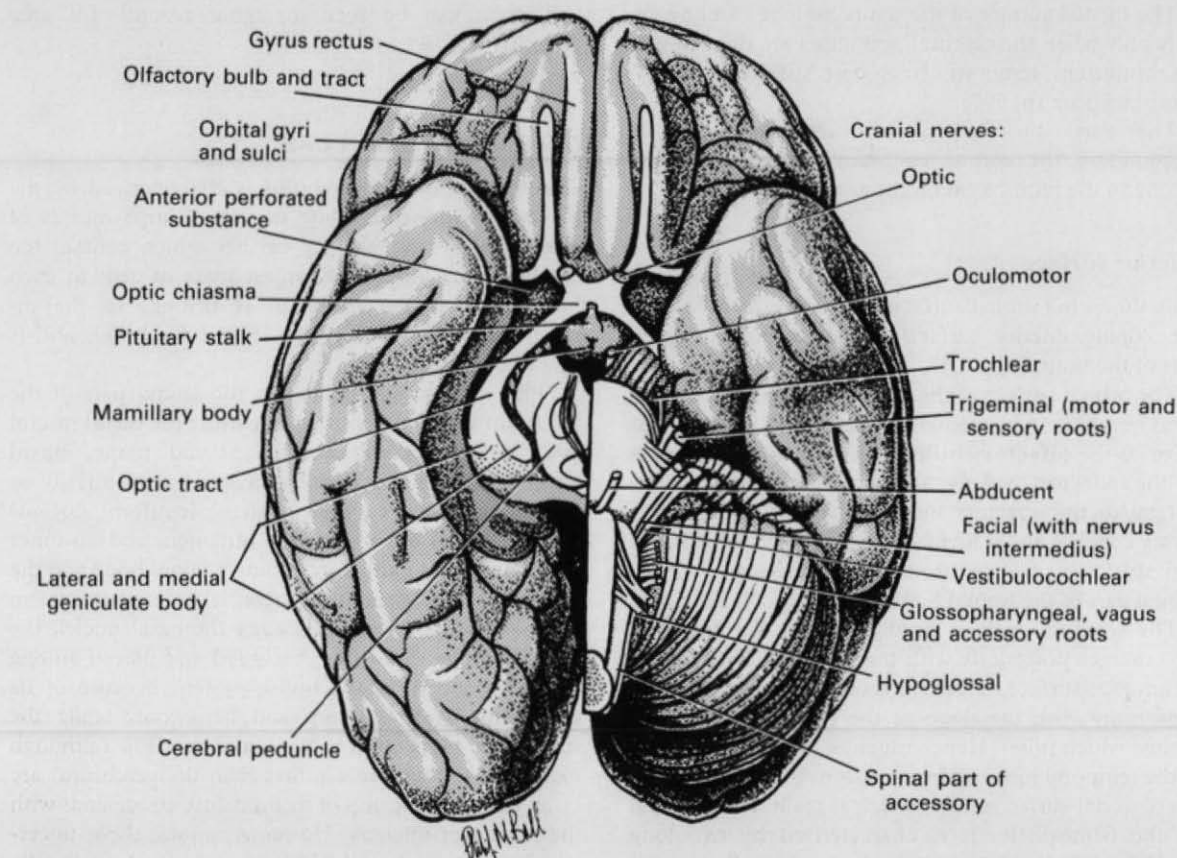


Fig. 7.4 Inferior surface of the brain. All the cranial nerves are intact on the left side. The right half of the brainstem has been removed by transection through the midbrain, together with part of the temporal lobe.

nated fibres which, by passing through the anterior part of the internal capsule, give the area a striated appearance.

As noted above the corpus striatum is the collective name for the caudate nucleus and the putamen part of the lentiform nucleus.

The **amygdaloid body** (often called 'the amygdala' by clinicians) consists of several nuclear masses and is connected with the tip of the tail of the caudate nucleus in the roof of the inferior horn of the lateral ventricle. It is functionally part of the limbic system (p. 588).

The **claustrum** is a thin lamina, circular in outline and curved into a saucer-shape. It lies lateral to the putamen, and although easy to identify in horizontal or coronal sections (e.g. Fig. 7.7) its significance is unknown.

Other *functional* components of the basal nuclei are considered elsewhere: the subthalamic nucleus on page 594, and the substantia nigra on page 606.

Functionally the basal nuclei exert a supraspinal control over skeletal muscle movements by influencing their rate, range and co-ordination. The corpus striatum, often called simply 'the striatum' by neurologists, can be regarded as the input side of the basal nuclei, receiving fibres mainly from the cerebral cortex, thalamus and substantia nigra. The globus pallidus ('the pallidum') is the output side, sending fibres to the thalamus, and also to the subthalamic nucleus, substantia nigra and the reticular formation. The fibres to the thalamus run in two large bundles, the *ansa lenticularis* and the *ansa fascicularis*, which pass ventral and dorsal to the subthalamic nucleus respectively. The *ansa fascicularis* passes through the fibres of the internal capsule, as does another bundle, the *subthalamic fasciculus*, interconnecting the globus pallidus and the subthalamic nucleus. Thus there are, for example, cortico-striato-pallido-thalamo-cortical pathways by which these subcortical cell groups can exert their influence on movement.

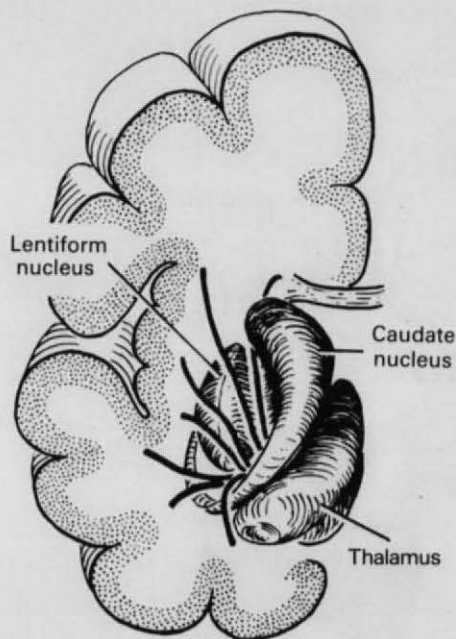


Fig. 7.5 Left thalamus and basal nuclei, viewed from behind. The heavy lines indicate the disposition of fibres of the internal capsule and corona radiata.

Different pathways involve different transmitters which include acetyl choline, dopamine, glutamate, serotonin and GABA. The commonest disease of the basal nuclei is parkinsonism, characterized by tremor, rigidity and akinesia; there is a decrease of dopamine in the nigro-striatal pathway.

The **white matter** of the cerebral hemisphere is made up of fibres belonging to three main groups.

Commissural fibres join the cortices of the two hemispheres. Most of them are gathered together in the *corpus callosum*; a few lie in the *anterior*, *posterior* and *habenular commissures*. They radiate widely and symmetrically through the white matter of the hemispheres.

Association (arcuate) fibres are confined to their own hemisphere, in which they connect different parts of the cortex.

Projection fibres are those which join the grey matter of the hemisphere with subcortical nuclei in the hemispheres and with nuclei in the brainstem and spinal cord. The verb 'project' is often used to indicate a connexion between one structure and another, e.g. the caudate nucleus projects to the putamen, meaning that the axons of the cell bodies in the caudate nucleus pass to make synaptic connexion with cell bodies in the putamen. In the base of the hemisphere a major collection of projection fibres lies lateral to the thalamus and

the head of the caudate nucleus, forming the *internal capsule*. The lentiform nucleus lies lateral to the internal capsule and the tail of the caudate nucleus curls around, also lateral (Fig. 7.5). From the internal capsule the fibres radiate upwards and outwards in the shape of a curved fan to reach the cortex and similarly pass from the cortex down to the capsule; this fan-shaped arrangement is the *corona radiata*. Fibres of the corpus callosum intersect it.

Internal capsule

The **internal capsule** consists of afferent fibres passing up to the cortex from cell bodies in the thalamus, and of efferent fibres passing down from cell bodies in the cortex to the cerebral peduncle of the midbrain. It lies within the concavity of the C-shaped caudate nucleus, which separates it from the C-shaped concavity of the lateral ventricle (Figs 7.5 and 7.7).

The internal capsule is seen in a typical horizontal section through the hemisphere (e.g. at a level through the interventricular foramen and the pineal body) as a band of white matter that is not a straight line but bent into a lateral concavity by the convex medial border of the lentiform nucleus (i.e. by the globus pallidus). Because of this almost L-shape the internal capsule is described as having an anterior limb, genu and posterior limb, and there are also two other portions posteriorly: the sublentiform and retrolentiform parts.

The **anterior limb** lies between the head of the caudate nucleus medially and the lentiform nucleus laterally. It contains *frontopontine fibres* from cell bodies in the frontal cortex. They pass down below the thalamus into the cerebral peduncle, where they occupy the medial third of the base of the peduncle. They arborize round the pontine nuclei. The anterior limb also probably contains fibres running from the frontal eye field to the oculomotor nucleus, concerned with the accommodation-convergence reflex (p. 518).

The **genu** is the region of the bend in the capsule (as seen in horizontal section), at the apex of the globus pallidus. Its principal constituents are the **corticoclear fibres** which pass from the cerebral cortex to the motor nuclei of cranial nerves in the brainstem (p. 612).

The **posterior limb** lies between the thalamus medially and the lentiform nucleus laterally. Occupying the *anterior two-thirds of the posterior limb* (right behind the corticonuclear fibres in the genu) are the **corticospinal fibres**. From cell bodies in the cortex the fibres pass down through this part of the capsule, then through the brainstem to the lower medulla where most of them decussate to form the **lateral corticospinal tract** and eventually arborize with the anterior horn

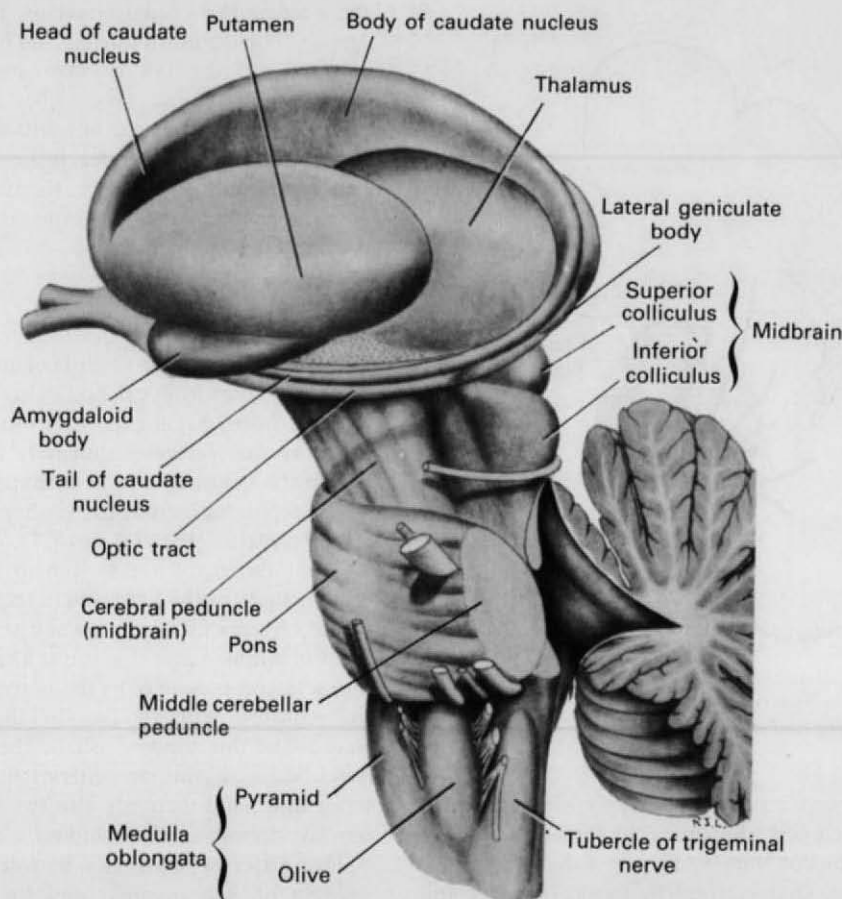


Fig. 7.6 Left basal nuclei and the brainstem from the left. The left half of the cerebellum has been removed by transecting the left cerebellar peduncles.

cells that innervate skeletal muscle. Thus passing through a small part of the internal capsule — genu and anterior two-thirds of the posterior limb — are the *motor fibres that control all the skeletal muscle in the body*. The head (corticospinal) fibres lie most anteriorly and immediately behind them are corticospinal fibres for the arm, hand, trunk, leg and perineum in that order from front to back. (In the cerebral peduncle of the midbrain the head fibres lie medially and the fibres for the perineum laterally, in the same order). It is in this part of the internal capsule that *haemorrhage or thrombosis of a striate artery commonly occurs*. The muscles of the opposite side of the body are thus paralysed; they become spastic with increased stretch reflexes, the signs of an upper motor neuron lesion (p. 625). Fibres from the speech (Broca's) area are interrupted in lesions of the left internal capsule; thus loss of speech accompanies hemiplegia of the right side of the body. By reading

this paragraph you have read about some of the most important facts in the whole of human anatomy.

Beside and behind the corticospinal fibres in the posterior limb of the capsule there are **thalamocortical fibres** passing from cell bodies in the thalamus to the cerebral cortex. These include sensory fibres mediating impulses derived from the opposite side of the body which run upwards through the corona radiata to the sensory cortex. There are also large numbers of *corticopontine fibres*.

In the **retrolentiform part** of the capsule, at the posterior end of the lentiform nucleus, are parieto-, occipito- and temporopontine (corticopontine) fibres which will occupy the lateral third of the base of the cerebral peduncle. But much more importantly, this part of the capsule contains *visual fibres* passing from cell bodies in the lateral geniculate body to the visual area of the cortex as the **optic radiation** (p. 587). A

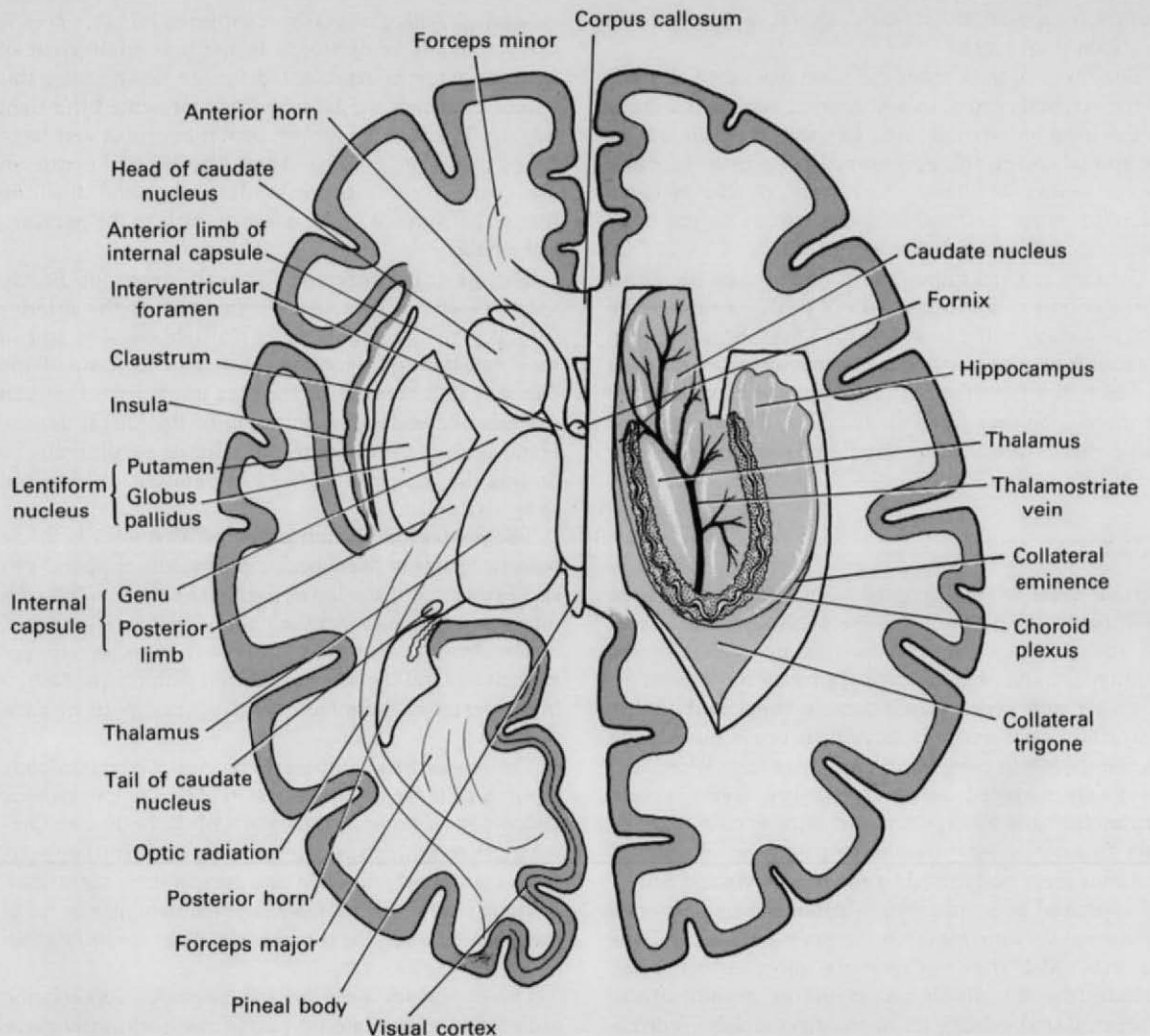


Fig. 7.7 Horizontal sections through the cerebral hemispheres, on the left side level with the interventricular foramen and on the right at a slightly higher level with dissection to open up the lateral ventricle.

further group of fibres runs from the medial geniculate body below the posterior end of the lentiform nucleus, so forming the **sublentiform part** of the capsule. These are the fibres of the **auditory radiation** which reach the auditory area of the cortex in the superior temporal gyrus (p. 586).

Although the corticopontine fibres (about 20 million) form the largest group of internal capsule components, the corticonuclear, corticospinal and thalamocortical fibres and those of the optic radiation are of greater clinical importance, though much smaller in number.

The **corpus callosum** (Fig. 7.3) consists of a mass of 100 million commissural fibres, each of which

extends from cortex to cortex between symmetrical parts of the two hemispheres. It commences at the anterior commissure, at the upper end of the lamina terminalis of the diencephalon and, traced from here to its termination, it becomes increasingly thicker. It is described as having four parts: the rostrum, genu, body and splenium. From the anterior commissure the mass passes upwards and forwards as the **rostrum**. It now takes a sharp bend backwards as the **genu**. From here it is gently convex upwards (the **body** of the corpus callosum) and it ends posteriorly as a thick rounded free border, the **splenium**. The corpus callosum can be seen by separating the two hemispheres, and its cut

surface is exposed in a midline sagittal section through the brain (Fig. 7.11).

The fibres of the corpus callosum extend to all parts of the cerebral cortex. In a horizontal section the fibres of the genu are seen arching forwards on each side to the frontal cortex; this appearance gives them the name *forceps minor*. Similarly, the fibres of the massive splenium curve backwards symmetrically to the occipital cortex, forming the *forceps major* (Fig. 7.7).

Between *forceps minor* and *forceps major* the fibres of the corpus callosum spread out to the cortex on the lateral surface of the hemisphere. They pass across the anterior horn and body of the lateral ventricle, for each of which they form the roof. As they turn down into the temporal lobe they form the lateral wall of the inferior and posterior horns of the lateral ventricle, where they are known as the *tapetum*.

CORTICAL AREAS

Certain areas of the cerebral cortex have long been identified with specific functions. Although these areas are still clinically relevant, modern investigations are modifying traditional concepts as far as the separation of motor and sensory functions is concerned. Many motor fibres, for example, have their origin outside the traditional motor cortex and some arise from what were previously regarded as purely sensory areas. A new terminology has emerged, and it is now customary to refer to a combined '*sensorimotor cortex*', subdividing it into four areas designated by the letters Ms and Sm — the capital M or S indicating whether the association is predominantly with motor or sensory functions. Thus the area MsI (first or primary motor sensory area) includes the old 'motor and premotor' regions of the precentral and other gyri of the frontal lobe (corresponding to areas 4 and 6 as described by Brodmann in his now classical study of cortical histology). The area MsII (the supplementary motor area) is on part of the medial surface of the frontal lobe (part of areas 6 and 8). Similarly SmI (first sensorimotor area) includes most of the postcentral gyrus (areas 3, 1 and 2) and its extension on to the medial surface of the parietal lobe, and SmII is the lowest part of the postcentral gyrus (areas 40 and 43). These four main motor and sensory areas have many interconnexions, both within their own and with the opposite hemisphere.

The area MsI is where movements of the various parts of the body are initiated, and it receives its main inputs from the cerebellum and thalamus. Some of the cortical cells send their axons down as the corticonuclear and corticospinal (pyramidal) tracts (p. 612). MsII receives many fibres from the basal nuclei and is

concerned with postural mechanisms, but this area is not yet clearly understood. In the precentral gyrus of MsI the body is represented upside down along this cortex, although the face itself is represented the right way up. The face lies lowest, then the hand (a very large area), then arm, trunk and leg. The leg and perineum areas overlap the superior border and extend down on the medial surface of the hemisphere into the paracentral lobule.

The **motor (anterior) speech area** (of Broca, areas 44 and 45) is usually situated in the inferior frontal gyrus on the left side (in right-handed and in most left-handed people), below and in front of the face area and centred on the pars triangularis between the anterior and ascending rami of the lateral fissure. Damage to it produces motor aphasia — difficulty in finding the right words, but not paralysis of laryngeal musculature.

The **posterior speech area** (of Wernicke) is in the posterior parts of the superior and middle temporal gyri and extends into the lower part of the parietal lobe. Its integrity is necessary for the understanding of speech.

The **frontal eye field**, involved in voluntary eye movements and the accommodation pathway (p. 519), is in the centre of the middle frontal gyrus (parts of areas 6, 8 and 9).

The areas SmI and SmII receive a large thalamic input. SmI is for the appreciation of touch, kinaesthetic and vibration sense, and the parts of the body are represented in roughly the same way as in MsI. SmII appears to be associated with pain and temperature sensations. Although the *conscious appreciation* of pain may occur at the thalamic level, the cortex is necessary for its *localization*.

The **gustatory area** for the conscious appreciation of taste lies in the inferior part of the postcentral gyrus (frontoparietal operculum), near the tongue area of SmI.

The **auditory area** (areas 41 and 42) is mostly hidden in the lateral sulcus, in the anterior transverse temporal gyrus. It extends into the superior temporal gyrus below the sulcus, and is here surrounded by the auditory association area (area 22). These regions receive fibres from the medial geniculate body via the auditory radiation. The cochleae are bilaterally represented, so a lesion of one cortex does not cause deafness.

The **olfactory area** is in the uncus at the front of the parahippocampal gyrus (Fig. 7.3A) and adjacent parts of the cortex.

The **visual area** (area 17) is mainly on the medial surface of the occipital lobe in the depths of the calcarine sulcus; more precisely, it lies along the *lower lip of the anterior part of the sulcus and along both upper*

and lower lips of the posterior part, and it extends for a short distance (1 cm or so) on to the lateral surface of the occipital lobe as far as the *lunate sulcus*. The true visual area is characterized by a white line (*stria of Gennari*) which bisects the grey matter of the cortex; in cortical sections it is easily seen with the naked eye, hence the name 'striate cortex' often given to this area. The cortex adjacent to the striate part on the medial and lateral surfaces of the hemisphere (and which does not have the *stria*) forms the *visual association area* (areas 18 and 19).

Each visual area receives from its own half of each retina, i.e. it registers the *opposite visual field*. In each cortex the upper half receives from the upper half of each half-retina, the lower half from the lower half of each half-retina, i.e. the upper and lower *visual fields are crossed*. The macula registers at the posterior end of the visual area and more peripheral parts of the retina progressively more anteriorly. When thinking about visual anatomy, do not confuse parts of the *visual fields* with parts of the *retina*. The temporal (lateral) half of the visual field of one eye conveys its impressions to the nasal (medial) half of the retina of that eye; similarly the temporal half of the retina receives its impressions from the nasal half of the visual field.

Visual pathways

The peripheral nerves of ordinary sensation, with their cell bodies in posterior root ganglia, are represented in the visual pathway by the *bipolar cells* of the retina (Fig. 7.8A). These cells receive impulses from the *retinal rods and cones*. The bipolar cells synapse with *ganglion cells* in the inner part of the retina (next to the vitreous body, 1 cell for each cone, 1 cell for 80 rods). These are homologous with the second neuron cell bodies in the central nervous system in the other sensory pathways. Their axons run on the surface of the retina and enter the optic disc and so pass to the optic nerve.

The **optic nerve** is not a nerve in the sense of the other cranial and spinal nerves; it is an elongated tract of white matter stretched out from the brain and enclosed in the meninges thereof as far forward as its attachment to the sclera. Histologically it is identical with white matter of the central nervous system, and there is no effective regeneration when divided. In the orbit it is surrounded by a tube of dura mater and arachnoid, with cerebrospinal fluid in the subarachnoid space. At the optic foramen the dura and arachnoid leave it and the nerve, still sheathed in pia mater, passes up to meet its fellow at the **optic chiasma**, which is attached to the anterior part of the floor of the third ventricle.

In the chiasma the *nasal fibres* of each optic nerve *decussate* and pass into the *optic tract* of the opposite side; the temporal fibres from each retina pass on to their own side (Fig. 7.8A). Thus the right optic tract contains fibres from the right half of each retina, i.e. it carries impressions from the nasal field of the right eye and the temporal field of the left eye. Likewise, the left optic tract contains fibres from the left half of each retina and since there is no further decussation this holds true right back to the visual cortex.

Cortical pathways for common sensation consist of three neurons. They reach the opposite hemisphere by a *complete* decussation of the second order neurons. The visual pathway by the *half* decussation of its second order neurons at the chiasma achieves the same object. There is *complete crossing of the visual fields*. One hemisphere registers common sensation from the opposite half of the body and also from the opposite half of the visible environment.

The **optic tract** passes from the chiasma around the cerebral peduncle, high up against the temporal lobe and, reaching the side of the thalamus, divides into two branches. The larger of these enters the *lateral geniculate body*, in which the fibres synapse. These are visual fibres. The smaller branch (*superior brachium* — see below) passes down medially, between the lateral and medial geniculate bodies, and synapses in the superior colliculus and the pretectal nuclei; these are fibres mediating light reflexes (p. 518).

Blood supply. The optic tract is supplied chiefly by the anterior choroidal and posterior communicating arteries, the chiasma and intracranial part of the optic nerve by the anterior cerebral. In the orbit the nerve is supplied by the ophthalmic artery and, distally, by the central artery on its way to the retina.

The **lateral geniculate body**, which is a part of the thalamus, is a small rounded elevation below the pulvinar on the posterior surface of the thalamus; identify it by following the optic tract backwards into it (Fig. 7.4). From the ganglion cells of the second neuron (in the retina) axons pass in the optic nerve, chiasma and optic tract to synapse with cells in **six layers** of the geniculate body. The fibres from the half-retina of the same side (i.e. temporal fibres) synapse at layers 2, 3 and 5, those from the half-retina of the opposite side (i.e. nasal fibres) synapse at layers 1, 4 and 6. From these layers the cell bodies send their axons through the optic radiation to the occipital cortex (Fig. 7.7). Because these fibres are proceeding from the lateral geniculate body to the visual cortex which largely borders the calcarine sulcus, the optic radiation is sometimes called the *geniculocalcarine tract*.

The *superior brachium* is the name given to the small

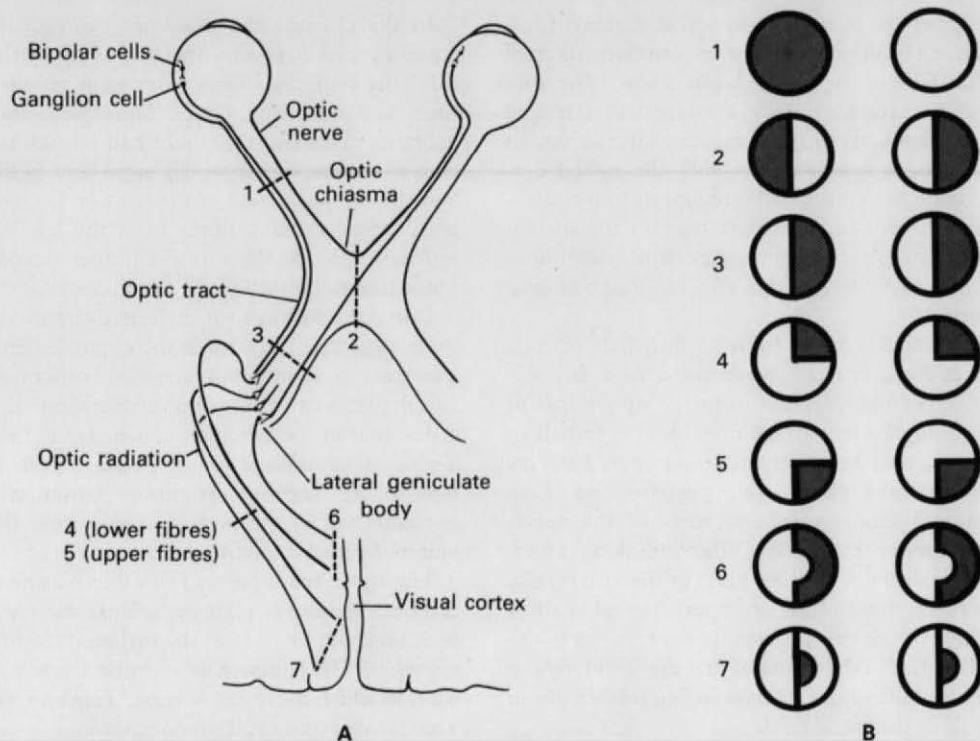


Fig. 7.8 Visual pathways. The numbers refer to the sites of lesions discussed on page 640.

(medial) branch of the optic tract. It passes down on the thalamus to the midbrain, where it ends in the tectum. The fibres in the superior brachium arborize around cells in the superior colliculus. The cell bodies in the *superior colliculus* send their fibres, by tectobulbar and tectospinal tracts, to motor nuclei in the brainstem and spinal cord for the mediation of **general light reflexes** (e.g. reflex blinking and jumping or turning away from a flash of bright light). The superior colliculi are united by the posterior commissure (at the entrance to the aqueduct, Fig. 7.11), and thus general body reflexes to light are usually bilateral. The special fibres concerned in the *pupillary light reflex* (p. 518) do not synapse in the colliculus, but pass bilaterally to each pretectal nucleus. The **pretectal nucleus** is a small group of cells lying in the tegmentum under the upper and lateral margin of the superior colliculus. It passes light impulses to each Edinger–Westphal nucleus and so to the sphincter pupillae. A lesion here produces the Argyll Robertson pupil; contraction to light is lost, but the pupil still contracts to accommodation and convergence. (The pathway of these reflexes is explained on p. 518.)

LIMBIC SYSTEM AND OLFACTORY PATHWAYS

Surrounding the corpus callosum and diencephalon are a number of features that have come to be known collectively as the **limbic system**. Because the olfactory tracts and its associated structures were originally included in this descriptive concept, much of its function was thought to be concerned with olfaction. However, this view is no longer tenable and it is now known to play a role in such abstract functions as behaviour, mood and memory; thus lesions of one of its major constituents, the hippocampus, result in loss of memory for recent events, although the memory of distant events is retained. Much remains to be discovered, but for the present purpose it is sufficient to note the component parts and to comment on selected items that have not been mentioned previously.

Limbic system

Apart from the olfactory nerves, bulb and tract (see below), the following are among the major components of the limbic system:

(1) The septal and piriform areas of cerebral cortex, near the lamina terminalis (anterior boundary of the third ventricle, p. 592)

(2) The uncus (p. 581), the insula (p. 578), and the cingulate and parahippocampal gyri (pp. 579 and 581)

(3) The amygdaloid body (p. 582)

(4) The hippocampus, fimbria, fornix and mammillary body (see below).

Some authorities would also include the hypothalamus and the anterior part of the thalamus in view of their functional connexions with limbic structures. There is as yet no universal agreement on what should be included.

Olfactory pathways

The olfactory tract, which is an elongated extension of the white matter of the brain (like the optic nerve), lies in the olfactory sulcus beside the gyrus rectus on the inferior surface of the frontal lobe (Fig. 7.4). Its anterior end is expanded as the **olfactory bulb**, containing the *mitral cells* with which the olfactory nerve filaments synapse after passing through the cribriform plate of the ethmoid (p. 473). The axons of the mitral cells run back in the tract to the anterior perforated substance, through which some of the fibres reach the region of the uncus (at the front of the parahippocampal gyrus, Fig. 7.4) and adjacent parts of the cortex. Other fibres make complex connexions with parts of the limbic system. Note that from the olfactory receptors in the nasal mucosa to the cortex there are two groups of neurons, and that the second neuron has reached the cortex without relay in the thalamus — a unique occurrence.

Further synapses connect the olfactory bulb with the hypothalamus and brainstem, as is the case with other sensory pathways (light, sound, taste, touch) for visceral and somatic effects, distinct from conscious appreciation.

Hippocampus

Just above the anterior part of the parahippocampal gyrus (here known as the subiculum) lies the hippocampal sulcus, which is projected into the floor of the inferior horn of the lateral ventricle as the **hippocampus**. Viewed from above the anterior part of it (the *pes hippocampi*) has the appearance of the knuckles of a clenched fist (Fig. 7.7). On its ventricular surface is a thin film of white matter, the *alveus*; its cell bodies are in the hippocampus and subiculum. The fibres of the alveus thicken medially to form the *fimbria*.

This breaks free from the hippocampus as the *crus* (posterior pillar) of the *fornix*. The *dentate gyrus* is a small part of the hippocampus which, as seen from the medial side, lies between the fimbria and the parahippocampal gyrus.

Fornix

The fornix is the great efferent pathway from the hippocampus. As a flat band continuous with the *fimbria*, it curves up behind the thalamus to join its fellow in a partial decussation across the midline, the *commissure of the fornix*. It is really a chiasma, and is an association tract rather than a true commissure. The conjoined mass of white matter, lying beneath the corpus callosum, is the *body of the fornix*. From it the conjoined *anterior columns* arch down in front of the anterior poles of the thalami, forming the anterior margins of the interventricular foramina (Fig. 7.11).

The columns of the fornix pass both anterior and posterior to the anterior commissure. The anterior fibres pass mainly to the *septal nuclei* near the lamina terminalis (*not* in the septum pellucidum). The posterior fibres pass directly to the thalamus or into the *mammillary body*. From the mammillary body fibres pass in the lateral wall of the third ventricle as the *mamillothalamic tract* to the anterior pole of the thalamus. Here they relay and the thalamic neurons send their fibres through the internal capsule to the *cingulate gyrus*.

On the upper surface of the corpus callosum is a thin film of grey matter, the *induseum griseum*, beneath which lie the *medial and lateral longitudinal striae*. These appear to be aberrant fibres of the fornix.

VENTRICLES OF THE BRAIN

The central nervous system is hollow; it develops from a neural tube whose cavity persists. The cavity is lined throughout with *ependyma*, a single epithelial-like layer of cells. The brain formation requires **cerebrospinal fluid**, whatever the reasons may be, and this fluid is produced within the cavity. The places where the cerebrospinal fluid is produced are the **ventricles**. In each ventricle the cavity comes to the surface without opening thereon; that is to say, the lining ependyma comes into contact with the surface pia mater, with no grey or white matter between. This is to allow the invagination of a mass of blood capillaries which thus becomes covered by pia and ependyma. This combination of *capillaries*, *pia* and *ependyma* constitutes the **choroid plexus** which secretes the cerebrospinal fluid. These vascular fringes invaginate the whole length of each surface encroachment of the ventricle.

Each cerebral hemisphere possesses its cavity, the *lateral ventricle*, and this comes to the surface at a curved slit, the *choroid fissure* (p. 597). The choroid plexus of the lateral ventricle is invaginated here. The diencephalon has a cavity, the *third ventricle*, that comes to the surface on its roof, and here are invaginated the two choroid plexuses of the third ventricle. The pons and medulla share a cavity which reaches the surface at the upper medulla, where the roof is invaginated by the right and left choroid plexuses of the *fourth ventricle*.

The choroid plexuses of the lateral ventricles are large and highly vascular; this pair secretes the bulk of the cerebrospinal fluid. Each lateral ventricle opens into the third ventricle by the *interventricular foramen*, and the choroid plexus of the lateral ventricle is continuous through this foramen with the very small amount of plexus in the third ventricle. From the third ventricle the aqueduct opens below into the fourth ventricle, which is a cavity in both pons and medulla. The plexus in the fourth ventricle is separate from that in the third and lateral ventricles and only makes a small contribution to the total amount of cerebrospinal fluid. Below the fourth ventricle the central canal extends as a tiny tube through the spinal cord into the upper end of the filum terminale. The only apertures in this system lie in the roof of the fourth ventricle, whence the cerebrospinal fluid escapes into the subarachnoid space (p. 613).

Modern methods of imaging, such as CT and MR scanning, have superseded older ventriculography which involved removing some cerebrospinal fluid and replacing it with air to obtain a radiotranslucent outline of the cavities. To interpret whether images of the ventricles are normal or not, it is essential to appreciate that the *midline* cavities (third ventricle, aqueduct and fourth ventricle) are symmetrical, but *asymmetry, especially posteriorly, is the rule in the lateral ventricles*. Look down on the vertex of any skull; it is asymmetrical in that one brow lies anterior to the other and the opposite occipital region lies more posteriorly than its fellow. The cerebral hemispheres are similarly asymmetrical and their contained lateral ventricles even more so.

The **lateral ventricle** is a C-shaped cavity, lined with ependyma, lying within the cerebral hemisphere. It does not lie entirely within the white matter of the hemisphere; indeed on its medial side it lies against the pia mater of the medial surface of the hemisphere, where pia mater and ependyma come into contact with each other. This line of contact is narrow, and curves around the top of the thalamus and the tail of the caudate nucleus, forming a C-shaped slit on the medial surface of the hemisphere, the **choroid fissure** (Fig. 7.3). The choroid fissure should be regarded as the medial wall of the body and inferior horn of the

ventricle. Into the choroid fissure the choroid plexus of the lateral ventricle passes, invaginating the pia mater and ependyma before it. The lips of the choroid fissure meet around the invaginated plexus, which thus lies hidden within the body and inferior horn of the ventricle.

In other places the cavity of the lateral ventricle lies further from the surface, so that grey matter at the bottom of a sulcus indents the cavity. Such sulci are the parahippocampal, calcarine and collateral, which show as convexities within the cavity of the ventricle. The caudate nucleus and thalamus also project into the cavity. Elsewhere the walls of the cavity are formed by white matter of the cerebral hemisphere.

The C-shaped cavity consists of the *body* of the ventricle and *anterior, posterior and inferior horns* (Figs 7.7 and 7.9). On the upward convexity is the body, projected forwards into a blind extremity, the anterior horn. These parts are floored in by the caudate nucleus and the thalamus and the roof is the corpus callosum and the fornix.

The **anterior horn** is bounded by the fibres of the corpus callosum that run laterally from the genu and rostrum (forceps minor). The bulbous head of the caudate nucleus lies in the floor, meeting the roof at an angle on the lateral side (Fig. 7.10), but separated from the roof medially by a thin partition between the fornix and corpus callosum, the *septum pellucidum*. Behind the anterior column of the fornix, between it and the anterior pole of the thalamus, is a small aperture, the **interventricular foramen** (of *Monro*), which leads from the lateral into the third ventricle. The choroid plexus in the body of the ventricle does not extend into the anterior horn but passes through the interventricular foramen (Figs 7.7 and 7.14) into the third ventricle.

The **body** of the lateral ventricle lies behind the level of the interventricular foramen. Its floor is the thalamus and body of the caudate nucleus, with the thalamostriate groove between them. The stria medullaris lies in the groove; it is a band of white matter running the whole length of the caudate nucleus, from the amygdaloid body at the tail to the anterior perforated substance at the head. Also in the groove (and more important) is the thalamostriate vein (Figs 7.10 and 7.21). The roof of the body is the corpus callosum with, on the medial side, the crus and body of the fornix.

If the corpus callosum is removed in a dissection the fornix is seen lying upon the thalamus, with the choroid plexus projecting between the two. It *appears* to be a floor structure of the body of the lateral ventricle. None the less it is actually a roof structure — a roof can collapse upon a floor and this has, so to speak, happened to the fornix. Through the medial wall of the body of the

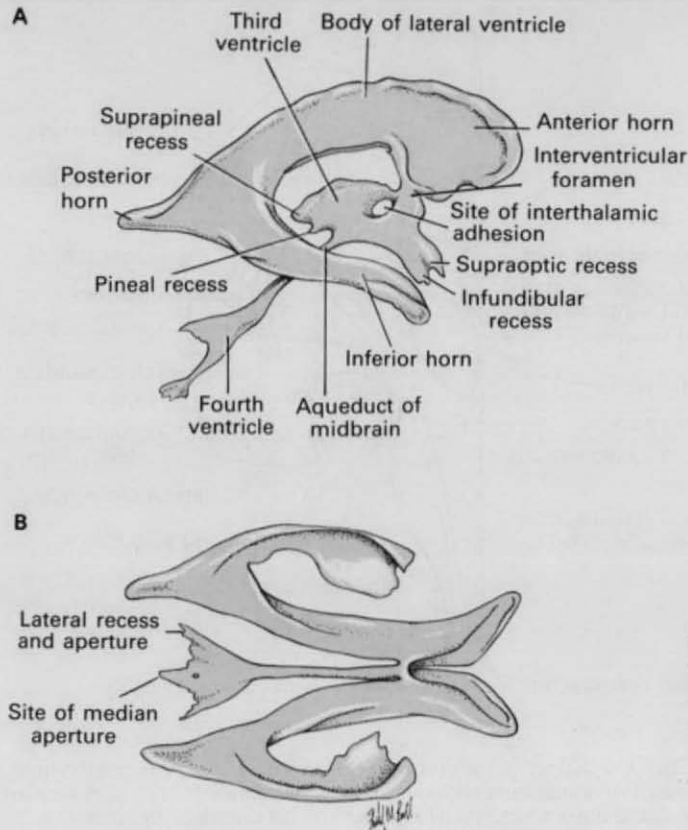


Fig. 7.9 Cast of the cerebral ventricles : **A** from the right, **B** from above.

ventricle, between roof (fornix) and floor (thalamus) the choroid plexus is invaginated, thrusting pia mater and ependyma before it. This is the upper part of the choroid fissure which is now seen to be limited anteriorly by the interventricular foramen (Figs 7.7 and 7.14).

From the body the cavity of the lateral ventricle arches downwards and then forwards into the temporal lobe as the inferior horn, and backwards into the occipital lobe as the posterior horn.

The **posterior horn** is the most variably developed and may even be absent. The floor is a convexity, the *collateral eminence*, produced by the collateral sulcus. The medial wall consists of two slight convexities: the upper is the *bulb of the posterior horn*, formed by fibres of the forceps major (from the splenium of the corpus callosum), and the lower is the *calcar avis*, formed by the calcarine sulcus. It is the calcar which, if well developed, obliterates the posterior horn. The roof and lateral wall is formed by the *tapetum* of the corpus callosum, with the optic radiation lying against the tapetum in the lateral wall (Fig. 7.7).

The **inferior horn** is the largest. Its floor consists medially of the hippocampus (p. 589) with, laterally, the *collateral eminence*, which expands posteriorly into the *collateral trigone* where the posterior and inferior horns diverge (Fig. 7.7). In the roof is the *tail of the caudate nucleus*, continuous anteriorly with the *amygdaloid body* which lies to the lateral side of the anterior perforated substance. The fimbria (p. 589) forms the lower lip of the choroid fissure in the inferior horn just as its continuation the fornix forms the upper lip of the fissure in the body of the lateral ventricle; they lie in continuity around the convexity of the C. Similarly, within the concavity of the C the *caudate nucleus* lies in continuity. Its bulbous *head* in the anterior horn and its thinner *body* in the floor of the body of the ventricle are continued into the *roof* of the inferior horn as an ever-diminishing *tail of the caudate nucleus*. At the extremity of the tail of the caudate nucleus is an expansion of grey matter, the *amygdaloid body*, which lies to the lateral side of the anterior perforated substance. It produces a shallow convexity on the roof at the tip of the inferior

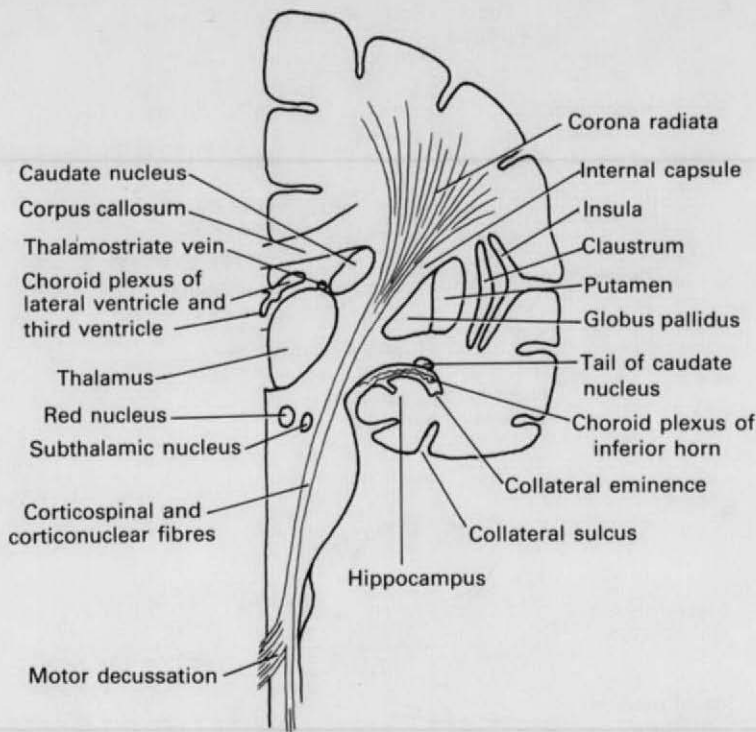


Fig. 7.10 Coronal section of the brain and brainstem. The section is not quite vertical but passes downwards and backwards to show the continuity of the corticospinal and corticonuclear fibres which run through the internal capsule to the brainstem.

horn, just above the pes hippocampi. These two projections often lie together, separated only by the choroid plexus. The inferior horn is closed laterally by the white matter of the tapetum.

The choroid plexus of the lateral ventricle is considered on page 590.

The C-shape of the lateral ventricle has certain implications. Structures around the convexity appear in the roof of the body and the floor of the inferior horn, structures in the concavity appear in the floor of the body and the roof of the inferior horn. Sections, be they vertical or horizontal, through the C-shaped formations must cut them in two places. Contained within the concavity of the C-shaped lateral ventricle is the C-shaped caudate nucleus, and contained within the concavity of the caudate nucleus is the white matter of the internal capsule.

DIENCEPHALON AND THIRD VENTRICLE

That part of the brain cranial to the midbrain is the forebrain. Developed as a single tube (the fore-end of the neural tube) its cranial end is formed by a thin plate

of grey matter, the *lamina terminalis*. Just to the caudal side of this lamina the side walls of the forebrain blow out into two enormous balloons, or vesicles, which become the cerebral hemispheres, already described. The remainder of the forebrain, relatively unexpanded, becomes the **diencephalon**, still closed anteriorly by the lamina terminalis. The cavity within its substance is the *third ventricle*, into which the lateral ventricles of the cerebral hemispheres open through the interventricular foramina. The diencephalon, enclosing this cavity, has two side walls, a floor and a roof. The floor and roof converge towards each other posteriorly, where they join the midbrain; and the cavity of the third ventricle is continued through the midbrain as a narrow canal, the *aqueduct* (of Sylvius). The aqueduct leads through the midbrain into the cavity of the fourth ventricle (Fig. 7.11).

The anterior wall and floor of the diencephalon can be seen in the undissected brain. The anterior wall is the **lamina terminalis**, a thin sheet which extends between the two hemispheres from the rostrum of the corpus callosum to the top of the optic chiasma (Fig. 7.11). It contains, in its upper part, the anterior commissure

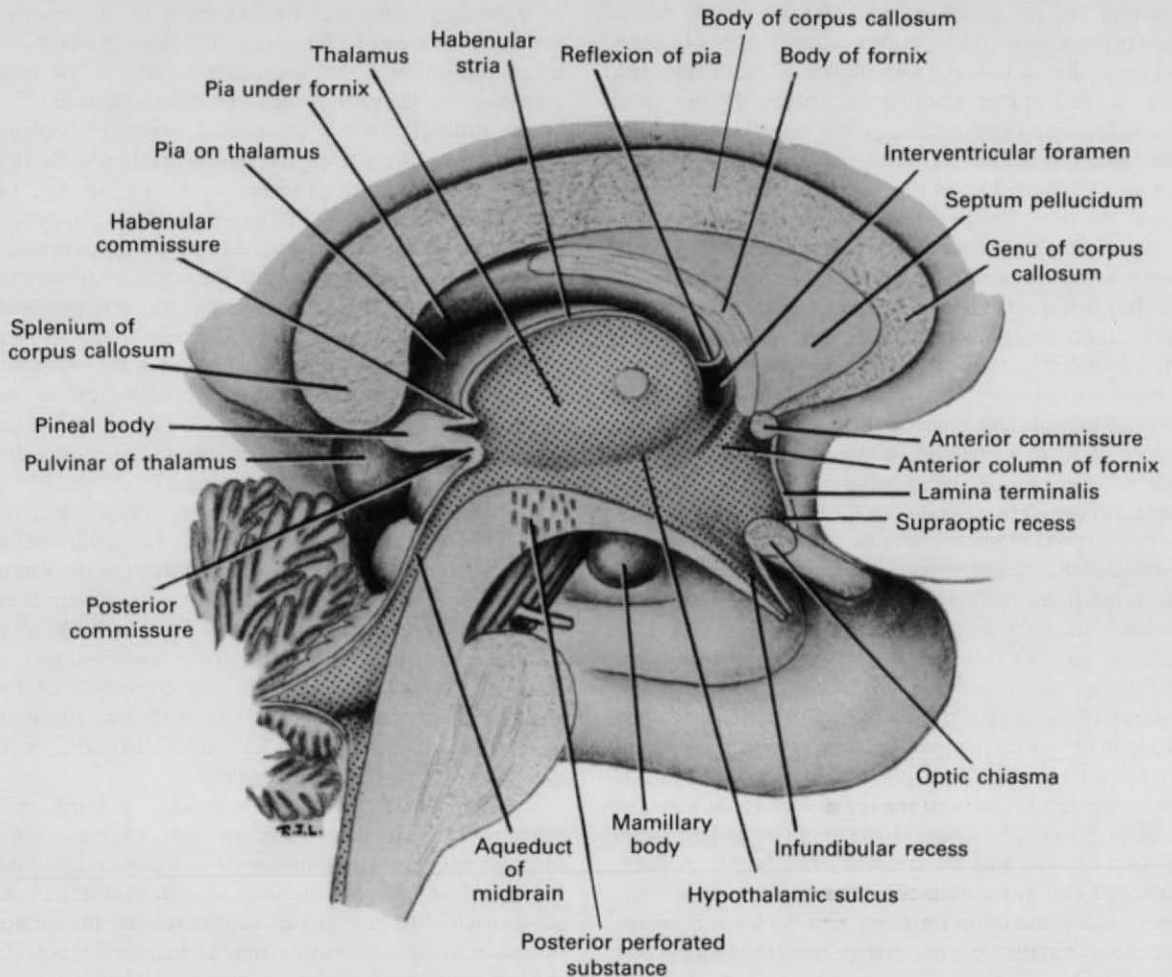


Fig. 7.11 Third ventricle and adjacent structures in sagittal section. The ependyma is stippled. The pia mater on the upper surface of the thalamus (lower layer of tela choroidea) is reflected on to the lower surface of the fornix (upper layer of tela choroidea) to form the roof of the interventricular foramen. Above and behind the thalamus the pia has been cut flush with the habenular stria, so the choroid plexus and suprapineal recess have been removed.

which joins the two piriform areas of the cortex. The floor, seen from below as the floor of the third ventricle, extends from the optic chiasma, tuber cinereum and infundibulum, and mamillary bodies to the posterior perforated substance, where the floor joins the tegmentum of the cerebral peduncles (Fig. 7.4). The anterior wall and floor can be seen cut through in a median sagittal section through the third ventricle; this section exposes the side wall of the diencephalon (Fig. 7.11).

In such a section a thin partition, the **septum pellucidum** is seen connecting the rostrum, genu and front of the body of the corpus callosum on the one hand to the anterior column of the fornix on the other. This is a

part of the medial surface of the hemisphere cut off by the backward growth of the corpus callosum; its function is unknown. The septum consists of two layers that may be adherent; when they lie apart the closed space between them is the *cavity* of the septum pellucidum; it has no connexion with the ventricular system and the term 'fifth ventricle' sometimes applied to it, should therefore be avoided. The cavity is lined with pia mater, not ependyma.

The **third ventricle** (Fig. 7.11) is a slit-like space, lying in the sagittal plane. Much of the lateral wall is occupied by the thalamus, a rounded mass of grey matter that bulges convexly into the ventricle. The two thalami often (60% of brains) become gummed

together at the *interthalamic adhesion*. It is not a commissure and there is no interchange of fibres between the two sides. The adhesion, when present, gives a fenestrated shadow in images of the third ventricle. The *hypothalamic groove* curves down from the interventricular foramen below the thalamus towards the aqueduct of the midbrain. A sagittal image shows the lateral bulge produced by the groove.

Below the hypothalamic groove the side wall slopes down to the floor. This region, including the floor, is the **hypothalamus** (Figs 7.11 and 7.12). The caudal part of this area that merges with the midbrain is the subthalamus, one of whose principal features is the *subthalamic nucleus*. In coronal sections through the internal capsule and brainstem (Fig. 7.10), this nucleus is seen easily as a small lens-shaped body on the medial side of the capsule, lying adjacent to the substantia nigra. It belongs functionally to the basal nuclei (p. 581).

The **hypothalamus** contains various cell groups, in particular the *supraoptic* and *paraventricular nuclei* whose axons run in the pituitary stalk into the *posterior lobe* of the pituitary (p. 569), and other cells whose processes enter the pituitary stalk to deliver their neurosecretory material to the *hypophyseal portal system* of blood vessels for the control of the anterior lobe. Yet other cells have long axons that pass by the *spinal sympathetic tract* to preganglionic cells in the lateral grey columns of the thoracic and upper lumbar parts of the spinal cord (p. 30).

Behind the optic chiasma the (hollow) *infundibulum* projects downwards to become the (solid) *pituitary stalk*. Behind the infundibulum the upper surface of the floor slopes smoothly upwards and backwards to the aqueduct, but the external surface is marked by the pair

of *mamillary bodies* and behind them by the *posterior perforated substance*. The part of the floor between the infundibulum and the mamillary bodies is the *tuber cinereum*, and the part of the tuber cinereum at the base of the infundibulum is the *median eminence* — highly important as the site of the neurosecretory cells that control the anterior pituitary, and one of the few regions with no blood/brain barrier (p. 600). The dependent mamillary bodies and the posterior perforated substance make no mark inside the ventricle. From the indentation of the optic chiasma the anterior wall (lamina terminalis) passes up. The tiny angle between the lamina terminalis and the chiasma is the *supraoptic recess*, and the hollow in the infundibulum is the *infundibular recess*. Attached behind the upper end of the lamina terminalis is the *anterior commissure*, a rounded cord that joins the two piriform areas of cortex. It is a commissure of the archaicopallium (p. 599). Behind this the conjoined anterior columns of the fornix lie in contact before they diverge to sink down into the lateral wall of the ventricle. Behind each anterior column is an *interventricular foramen*, ependyma-lined and roofed in by bare pia mater sweeping from the under surface of the body of the fornix to the upper surface of the anterior pole of the thalamus. This is the anterior limit of the *tela choroidea* (Figs 7.11 and 7.14), the name given to a double fold of pia mater.

The cavity of the third ventricle is lined with ependyma, continuous through the interventricular foramen with that lining the lateral ventricle and through the aqueduct with that lining the fourth ventricle. As in all ventricles, the lining of ependyma reaches the surface pia mater to allow for invagination of a choroid plexus. In the third ventricle this place is the narrow roof.

Attached to the upper curvature of the bulging thalamus is a thin band of white matter, the *medullary stria* of the thalamus. Right and left striae join posteriorly in a U-shaped loop, the *habenular commissure*. Anteriorly the striae pass from the thalamus below the interventricular foramen alongside the anterior column of the fornix and so to the piriform area. The habenular commissure is probably olfactory, like the anterior commissure. The drawing back into the U-shaped loop exposes the narrow *roof* of the third ventricle (Fig. 7.13).

The upper surface of each thalamus alongside the medullary stria is on the surface of the diencephalon; it is covered with pia mater. This pia mater is attached to the medullary striae and sweeps across between them to roof in the third ventricle, back to the habenular commissure. This pial roof is lined with ependyma. It is variably slack towards its posterior end and bulges back as the *suprapineal recess* (Fig. 7.12). The whole length of the roof is invaginated by the pair of (small) *choroid*

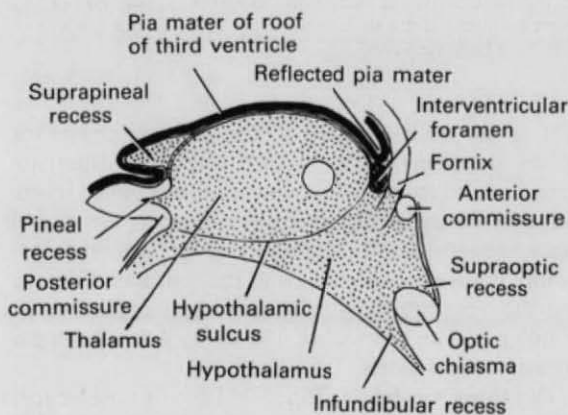


Fig. 7.12 Outline of the cavity of the third ventricle, with the ependyma stippled. The pia mater (in heavy line) from the pineal to the anterior column of the fornix alone roofs in the third ventricle and the interventricular foramen.

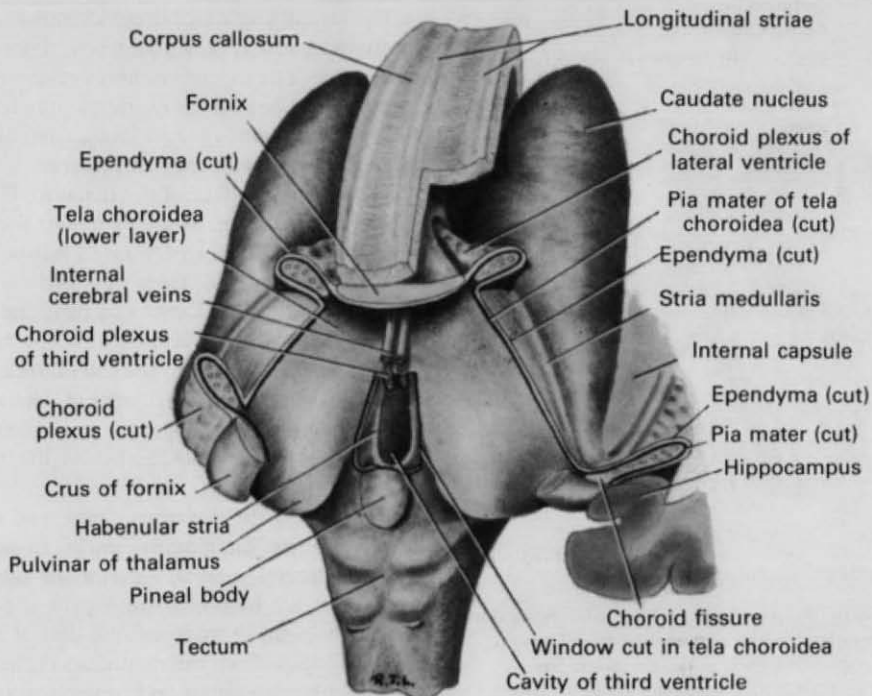


Fig. 7.13 Lower layer of the tela choroidea, from above and behind, exposed by removal of the body of the fornix and the posterior part of the corpus callosum.

plexuses of the third ventricle, which hang down as slender fringes inside the cavity.

The pial roof (Figs 7.11 and 7.12) extends forward to the anterior pole of the thalamus, sweeps across to the anterior column of the fornix to close the interventricular foramen, thence no longer lined with ependyma it passes back on the under surface of the fornix as the upper layer of the tela choroidea, out of contact with the third ventricle (Figs 7.11 and 7.14).

Attached to the habenular commissure the **pineal body** projects back, lying above the superior colliculi between the posterior parts of the thalami, just below the splenium (Figs 7.11 and 7.24). It is a soft conical body, less than half a centimetre long, and is one of the few regions with no blood/brain barrier (p. 600). It is noteworthy for the number of *corpora amylacea* it contains. These calcify, and to such an extent that after the age of forty years they normally throw a shadow in radiographs of the skull. Such calcified particles (known to the ancients) were called brain sand; they occur also in the choroid plexuses. A displaced calcified pineal indicates a space-occupying lesion above the tentorium. The pineal cells secrete melatonin (a hormone related to serotonin), which in animals and probably in man also has an antigonadotrophic action.

The stalk of the pineal is attached also to the poster-

ior commissure, which connects the two superior colliculi above the entrance to the aqueduct. Between the habenular and posterior commissures the pineal stalk is hollowed out as the *pineal recess* (Fig. 7.12), not to be confused with the larger *suprapineal recess* between the pineal body and the habenular commissure).

The **thalamus** is seen in horizontal and coronal sections buried in the cerebral hemisphere (Figs 7.7 and 7.10), and by its connexions with the sensory parts of the internal capsule it appears to be part of the hemisphere. This is not so; it is part of the wall of the diencephalon, the part of the forebrain which does not expand into the cerebral hemispheres. However, as the cerebral hemispheres develop, new cells in the thalamus send fibres up to the sensory cortex and in this way the 'neothalamus' becomes incorporated in the pathways leading to the cortex. The 'neothalamus' lies on the lateral side.

The mass of grey matter making up the thalamus is roughly wedge-shaped. The medial walls of the two thalami lie parallel, near each other across the third ventricle, where in two-thirds of cases they are joined by the *interthalamic adhesion*. This part of the medial surface is covered with the ependyma of the third ventricle. Behind this the medial surface diverges from the midline and expands into a large posterior convexity,

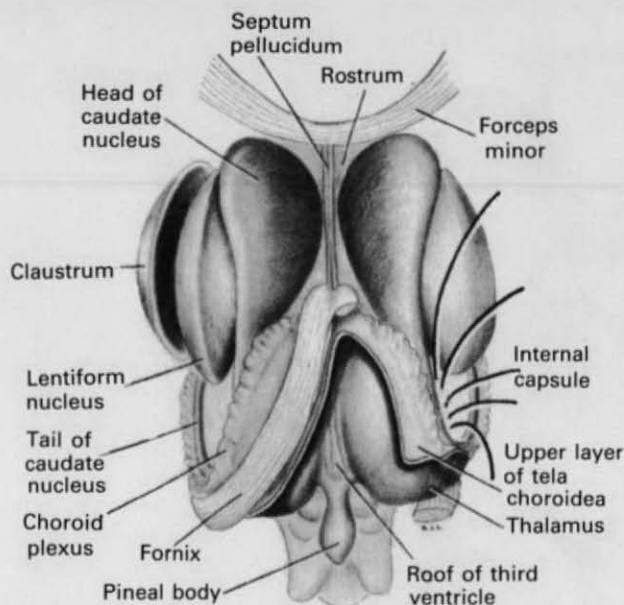


Fig. 7.14 Basal nuclei, thalamus and tela choroidea, from above and behind. The upper layer of the tela, here partly cut away, clothes the lower surface of the body of the fornix and the splenium of the corpus callosum. The lower layer of the tela clothes the thalami and roofs in the third ventricle (for simplicity the suprapineal recess has been omitted). The two layers of the tela form a triangular pouch, open posteriorly across the base. Each side of the pouch lies at the choroid fissure, where it is 'pushed' into the body of the lateral ventricle by the choroid plexus. The apex of the pouch forms the roof of the interventricular foramen. Compare with Figures 7.11 and 7.13.

the *pulvinar*; the lateral geniculate body (p. 587) bulges down from its lateral part (Figs 7.4 and 7.24). The *medial geniculate body*, a thalamic nucleus which relays auditory impulses, is separated from the main mass of the thalamus and lies on the midbrain (Fig. 7.4 and p. 607). It receives fibres from the cochlear nerves by way of the nuclei of the nerves and the lateral lemniscus, and relays them through the sublentiform part of the internal capsule to the auditory cortex below the lateral fissure (p. 585). It is thus a cell station on the auditory pathway.

The superior surface of the thalamus is convex and triangular in outline, tapering forward from the large pulvinar to the small blunt anterior pole (Fig. 7.14). The superior surface and the posterior surface (pulvinar) of the thalamus are on the external surface of the diencephalon itself. They are covered in pia mater. An oblique strip along the lateral margin of the superior surface lies in the lateral ventricle. Covered with ependyma, this narrow strip belongs rather to the hemisphere than to the diencephalon. The body and tail of the caudate nucleus are in contact here with the lateral margin of the thalamus (Fig. 7.6).

The lateral surface of the thalamus is bevelled by the internal capsule (Fig. 7.10), whose descending fibres lie in contact. The ascending fibres of the internal capsule arise further back from numerous nuclei in this lateral part ('neothalamus') and make the neothalamus all one, as it were, with the hemisphere.

The inferior surface of the thalamus is narrower than the superior surface. Medially it joins the hypothalamus down to the posterior perforated substance in the floor of the third ventricle. Here pass various striate arteries and thalamic veins. Lateral to this, and posterior too, the lemnisci of the tegmentum (p. 606) enter the thalamus and attach it to the top of the midbrain.

All four surfaces (medial, inferior, lateral and superior) of the thalamus converge to the small blunt anterior pole. Covered in ependyma this lies at the interventricular foramen.

Structurally the thalamus consists of a large number of cell groups, the *thalamic nuclei*. In simplified terms there are lateral, medial, anterior and other nuclei, with numerous subdivisions. Among the most important is the *ventroposterior* part of the *lateral nucleus*, which receives inputs from the medial and spinal lemnisci and the reticular formation and projects to sensory areas of the cerebral cortex, thus making the thalamus a great cell station on sensory pathways. Other parts of the lateral nucleus receive fibres from the dentate nucleus of the cerebellum and the globus pallidus and project to the motor areas of the cortex, so contributing to motor control. Some medial cell groups receive fibres from the hypothalamus and corpus striatum and have reciprocal connexions with the frontal lobes; they appear to be concerned with emotional responses and memory. The hypothalamus also sends fibres to the anterior thalamic nucleus via the mamillothalamic tract, and the nucleus projects to the cingulate gyrus; it is part of the limbic system (p. 588). Other thalamic nuclei have connexions with the reticular formation (p. 611). The medial and lateral geniculate bodies are specialized parts of the thalamus concerned with hearing and vision respectively (see above and p. 587).

The pia mater over the thalamus originally invested the cylindrical tube of the diencephalon, as, for example, it still invests the mesencephalon or the spinal cord in the adult. Over the dorsal surface of the diencephalon, however, the corpus callosum and fornix extend back. Each of these is clothed in pia mater. Thus the pia mater is folded back on itself from the interventricular foramina (Fig. 7.14). Behind this it extends over the roof and dorsal surface of the thalamus and continues down over the pineal body and tectum of the midbrain. From the interventricular foramina it likewise extends backwards on the under surface of fornix and corpus callosum and is

reflected around the splenium of the latter to the upper surface of the body of the corpus callosum. Upper and lower layers of pia mater, thus lying in contact, are no more than the pia mater investing the surface of any part of the central nervous system; they are only lying in contact because the fornix and corpus callosum project back over the dorsal surface of the diencephalon. These two layers of pia mater are the **tela choroidea**. They are reflected, the upper on to the lower, between the inter-ventricular foramina and are similarly reflected on to each other at the lateral extent of the tela. This follows the line of the body of the fornix, which passes obliquely across the upper surface of the thalamus.

The layers are thus reflected on each other laterally along the lateral margins of the body of the fornix; the lower layer is attached to the upper surface of the thalamus as far laterally as this line. The tela choroidea thus forms a pouch, triangular in outline, apex forward (Figs 7.13 and 7.14). The base is open, where the two layers of pia mater part, the lower passing down over the back of the midbrain, the upper passing forwards on the corpus callosum around the splenium. The lateral reflexion of pia mater along the edge of the tela, between the body of the fornix and the upper surface of the thalamus, comes into contact with the ependyma lining the lateral ventricle. This is the upper part of the C-shaped choroid fissure, and into it is invaginated the *choroid plexus of the lateral ventricle*, pushing the conjoined pia mater and ependyma in advance of it into the cavity of the lateral ventricle. At the posterior margin of the inter-ventricular foramen the conjoined pia and ependyma of the medial wall of the lateral ventricle are traceable backwards into the conjoined pia mater and ependyma of the roof of the third ventricle. Here the conjoined pia and ependyma are invaginated by blood vessels to form the *choroid plexuses of the third ventricle*. These are much smaller, but each is continuous, right and left, with the plexus of the lateral ventricle (Fig. 7.13).

The *internal cerebral veins* run back on the pia mater of the inferior layer of the tela choroidea (Figs 7.13 and 7.21), on the roof of the third ventricle.

The **choroid fissure** is a C-shaped slit in the medial wall of the cerebral hemisphere, extending from the inter-ventricular foramen around the thalamus and cerebral peduncle as far as the uncus of the temporal lobe (Fig. 7.3A). Its convexity is contained by the body and crus (pillar) of the fornix, the fimbria and the hippocampus, its concavity is contained by the thalamus (upper and posterior surfaces) and the tail of the caudate nucleus. At the slit pia mater and ependyma come into contact with each other and both are invaginated into the lateral ventricle as the choroid plexus. The choroid fissure on the medial wall of the

hemisphere was originally on the roof of the cerebral vesicle, and the arrangement is better understood by considering the development.

DEVELOPMENT OF THE FOREBRAIN

The whole neural tube (p. 35) is hollow (as in any tube) and the cavity comes to the surface in two places, each on the dorsal surface of the tube. In these two places the ependyma lining the cavity of the tube lies in contact with the pia mater clothing the surface of the tube. The anterior of these two areas is destined to become the forebrain, the posterior the hindbrain (fourth ventricle).

The **forebrain** is limited by the *lamina terminalis*, which remains in situ in the adult. Across its dorsal margin lies a commissure connecting the two sides; this is the *anterior commissure* and persists as such. The roof, as already stated, is devoid of nervous tissue; here pia mater and ependyma blend. The side wall contains nerve cells that form the primitive thalamus.

From near the front end of the hollow forebrain right and left hollow diverticula grow out laterally, like bubbles. The thalamus lies behind (caudal to) these **cerebral vesicles** (Fig. 7.15), and this part of the forebrain remains relatively stable as the **diencephalon**. The cavities of diencephalon and cerebral vesicles communicate at the site of the future inter-ventricular foramen, in the side wall of the diencephalon.

As the cerebral vesicle grows out it takes the thin roof of the forebrain with it. Into the L-shaped roof thus produced a mass of blood capillaries, itself L-shaped, is invaginated to form a **choroid plexus**. The plexus is fed by an artery at its lateral extremity (the anterior choroidal artery) and it drains by a choroidal vein which runs back along the roof of the unexpanded diencephalon, to join with the vein of the opposite side.

The cerebral vesicles grow mightily, and become rotated, with their surfaces folded to accommodate themselves to the limits of the cranial cavity in which they develop. The thin roof-plate of the vesicle, with its invaginated choroid plexus, becomes compressed and distorted. The cerebral vesicles grow by multiplication of nerve cells in the grey matter on their surfaces. As new daughter cells appear their axons grow in two main ways: to produce commissural and association fibres, and to produce projection fibres. Both sets of fibres produce new complications. The *commissural* fibres form the *corpus callosum* and *association fibres* form the *fornix*. The former grows first forwards (the rostrum) then backwards (the genu, body and splenium) in conformity with the growth of the vesicles (cerebral hemispheres). The fornix is forced backwards by the backward growth

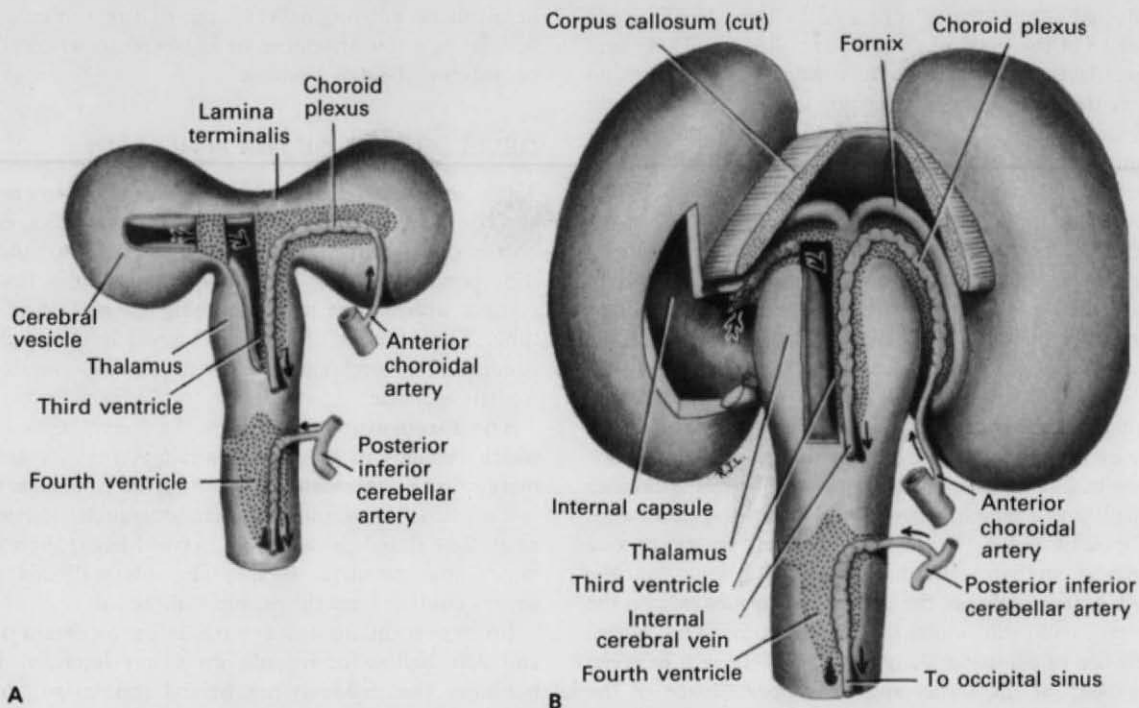


Fig. 7.15 Dorsal view of the developing cerebral hemispheres and the choroid fissure. In **A** the ependymal roof-plate of the forebrain is drawn out on the roof of the growing cerebral vesicle and is invaginated by the choroid plexus. This roof-plate of the early cerebral vesicle comes to lie on the medial side of the growing hemisphere, as in **B**, and it curves around the developing basal nuclei, thalamus and fibres of the internal capsule, forming the choroid fissure. The roof-plate is partly removed on the left side, and an arrow passes from the lateral ventricle (in the hemisphere) through the interventricular foramen into the third ventricle. Small arrows indicate the direction of blood flow in the choroid plexuses of the third and fourth ventricles. The cerebellum is omitted in order to show the roof and choroid plexus of the fourth ventricle.

of the corpus callosum, so that both come to overlie the roof of the unexpanded forebrain (diencephalon). The cerebral vesicles (cerebral hemispheres) grow caudally, then ventrally, and finally forward. The corpus callosum could only do this by cutting through the brainstem; hence its fibres, sweeping away to the temporal lobe, become heaped up into a thick mass posteriorly, forming the splenium. The fornix, on the other hand, consists of association rather than commissural fibres, and it parts from its fellow and sweeps around the side of the diencephalon to pass forwards into the temporal pole.

In addition to these commissural and association fibres, *projection fibres* pass down from the cortex of the developing cerebral vesicle into lower centres in the developing neural tube. These *corticospinal fibres* stream down alongside the thalamus. Meanwhile, ascending tracts are developing and extend up to new cells developing in the lateral wall of the thalamus. From these thalamic cells new fibres pass up to the cortex, establishing continuity between the lateral part of the thalamus and the cortex of the cerebral vesicle. The two

bundles, of ascending and descending fibres, fuse together into a mass of white matter, the *internal capsule* (p. 583). The ascending fibres of the internal capsule are connected with the thalamus; the descending fibres are closely applied to the thalamus; thus the thalamus, originally lying in the side wall of the diencephalon, becomes partly incorporated in the cerebral vesicle (hemisphere).

Meanwhile, cells have been dividing in the floor of the cerebral vesicle to produce the corpus striatum. Fibres of the internal capsule interrupt the continuity of this cell mass and almost completely separate the caudate from the lentiform nucleus. The fibres bulge the caudate nucleus (and lateral ventricle, in the floor of which it lies) convexly around their mass.

At the same time, the cerebral vesicle itself has been altering its position. Unequal growth on its surface forces the roof to the medial surface, and the curvature of the caudate nucleus and lateral ventricle around the fibres of the internal capsule is reflected in a similar curvature of the thin roof plate around the thalamus and internal capsule. Thus the original *dorsal* roof plate

of the vesicle (choroid fissure) becomes *medial and curved*; but the anterior choroidal artery still enters the distal extremity of the fissure and the choroid plexus of the cerebral vesicle is still in continuity with the choroid plexus of the diencephalon (third ventricle) at the point of junction of the original roof plates (interventricular foramen) (Figs 7.13 and 7.15).

Morphology

Certain parts of the cortex, notably the insula and piriform area, can be regarded as remnants of the primitive brain (*archaeopallium*). Anterior and posterior commissures unite the two halves. The anterior pole of the thalamus and the globus pallidus provide the subcortical nuclei. The *archaeopallium* was predominantly a smell brain. The contemporary cerebellum (p. 617) was mainly vestibular in its connexions (*archaeocerebellum*).

The huge growth of hemisphere which buries the insula is the *neopallium*. Its commissure is the corpus callosum and it is associated with the appearance of the putamen and caudate nucleus and the lateral nuclei of the thalamus. With the *neopallium* appear also the neocerebellum and the red and olivary nuclei.

The smell world has been replaced by a new sight, hearing and touch world, and fine co-ordinated movements have become possible.

BLOOD SUPPLY OF THE CEREBRUM

The cerebral hemispheres and the walls of the diencephalon are supplied from both the internal

carotid and vertebral systems. The arteries are directed in essence to the grey matter, which needs more blood than the white matter. Superficial cortical arteries supply the grey matter on the surface, perforating arteries supply the subcortical nuclei. Both sets of arteries send branches to the adjacent white matter.

An artery that has entered the surface of the brain from either of these sets is always an end artery (i.e. it has no precapillary anastomosis with its fellows), and thus cerebral softening follows its obstruction. Entering arteries invaginate a tubular prolongation of pia mater around them, forming a *perivascular space* that extends to the fine branches of the vessel.

The internal carotid and vertebral systems anastomose with each other around the optic chiasma and infundibulum of the pituitary stalk, forming the **arterial circle of Willis** (the French call it, more accurately, the polygon of Willis). The communicating vessels allow equalization of bloodflow between the two sides of the brain, and can allow anastomatic circulation if parts are occluded; however, this is not always effective due to the small size of some vessels. The circle is formed in the following way. The basilar artery from the vertebral system divides at the upper border of the pons into right and left *posterior cerebral arteries*. From each posterior cerebral a small *posterior communicating artery* runs forward through the interpeduncular cistern to join the *internal carotid artery* at the anterior perforated substance. Each internal carotid artery gives off an *anterior cerebral artery*; the circle of Willis is completed by the *anterior communicating artery*, a small

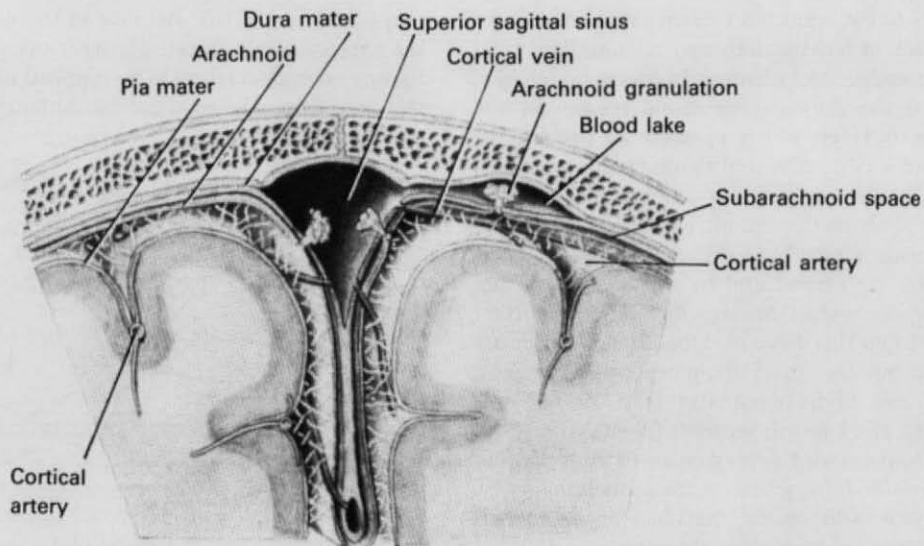


Fig. 7.16 Superior sagittal sinus, meninges and associated vessels in sagittal section of the cranial vault.

vessel that unites the anterior cerebrals in the chiasmatic cistern, below the rostrum of the corpus callosum. The only structures encircled by the circle of Willis are the optic chiasma and the pituitary stalk (Fig. 7.23). Rupture of an aneurysm of the arterial circle accounts for 90% of subarachnoid haemorrhages. Congenital aneurysms are more commonly found on the carotid part of the circle than the basilar part, and are most frequent at sites where vessels branch (e.g. anterior cerebral with anterior communicating, internal carotid with posterior communicating or middle cerebral) because here the tunica media is weakest.

Blood supply of the cerebral hemispheres

The arterial supply of the cerebrum is by *three cerebral arteries*, anterior, middle and posterior, as might be expected from the name cerebral, but there is also a contribution from a *fourth* artery, the *anterior choroidal* (although, unlike the other three, it does not supply the cerebral cortex). The former two are branches of the internal carotid, the posterior cerebral is the terminal branch of the basilar (from the two vertebrals), and the anterior choroidal arises from the termination of the internal carotid or its near neighbours, the middle cerebral or posterior communicating. The branches of the three cerebral arteries anastomose across the frontiers of their respective territories (Figs 7.17 and 7.18), on the surface of the pia mater, but sparsely and only by arterioles. Their perforating branches are invariably end arteries. The larger surface vessels have a sympathetic innervation, but after becoming intracortical they are not innervated.

Capillaries in the brain (and spinal cord) are characterized by lack of fenestrations and by abundant tight junctions (zonulae occludentes) between endothelial cells. This is the principal structural reason for the **blood/brain barrier** which operates to protect the internal environment of neural tissue by allowing only selected substances (amino acids, amines and sugars) to be transported across the endothelial cells. This protective mechanism is possibly assisted by a basal lamina that is thicker than usual and by the enveloping foot processes of astrocytes. Among the more important parts of the brain that have no blood/brain barrier are the posterior pituitary (p. 570), pineal body (p. 595), median eminence of the hypothalamus (p. 594) and the area postrema of the fourth ventricle (p. 611).

The **internal carotid artery** emerges from the roof of the cavernous sinus, gives off the ophthalmic artery, then curls back to lie on the front half of the roof. It then turns vertically upwards to the anterior perforated substance where it divides into middle and anterior

cerebral branches for the supply of the cortex. It here gives off also the striate arteries, the anterior choroidal artery, and the posterior communicating artery (Fig. 7.23).

The **middle cerebral artery** is the largest and most direct branch of the internal carotid (Fig. 7.23) and therefore most subject to embolism. It passes deep into the lateral sulcus to supply the cortex of the insula and overlying opercula. It reaches the lateral surface of the hemisphere by passing in the lateral sulcus, from which its branches emerge for the most part deep in the sulci and ramify over an area that falls short of the borders of the lateral surface by one gyrus or its equivalent breadth (Fig. 7.17). It does not reach the superior frontal gyrus or the inferior temporal gyrus. In its area of cortical distribution lie the *motor* and *sensory areas* for the opposite half of the body *excluding leg* and *perineum* (which are in anterior cerebral territory — see below) and the *auditory* and *speech areas*. For striate arteries see below.

The **anterior cerebral artery** leaves the internal carotid artery at the anterior perforated substance and passes forwards above the optic nerve (Fig. 7.23). It is connected to its fellow of the opposite side by the *anterior communicating artery*. It is distributed to the orbital surface of the frontal lobe and to the whole of the medial surface of the hemisphere above the corpus callosum as far back as the parieto-occipital sulcus. Its distribution extends over the superior border to meet the area supplied by the middle cerebral artery; it thus supplies the superior frontal gyrus and an equal zone behind this over the parietal lobe. The *motor* and *sensory areas* for the *opposite leg* and *perineum*, including the *micturition* and *defaecation centres*, lie in its territory (Figs 7.17 and 7.18). Because of the anastomosis via the anterior communicating artery, it is usually possible for one anterior cerebral to be supplied with blood from the contralateral internal carotid (although occasionally

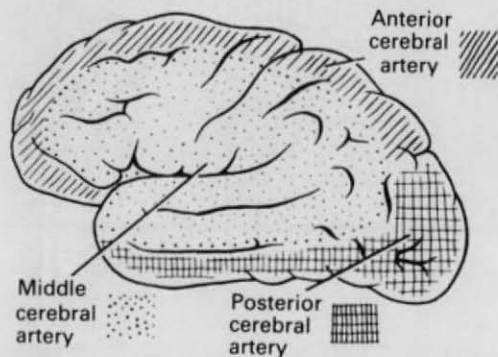


Fig. 7.17 Areas of arterial distribution on the lateral surface of the left cerebral hemisphere.

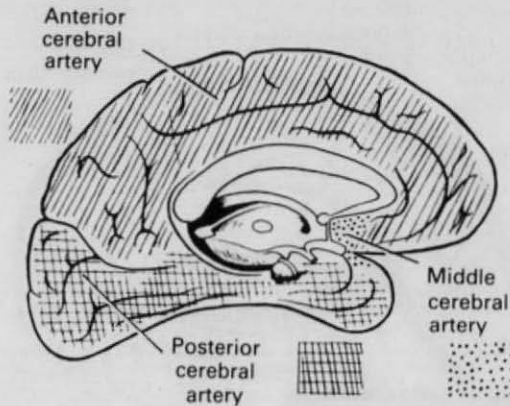


Fig. 7.18 Areas of arterial distribution on the medial surface of the left cerebral hemisphere.

both anterior cerebrals may arise from one carotid by a common stem).

The fact that the internal carotid gives origin to the anterior and middle cerebral arteries (supplying the sensorimotor cortex and internal capsule — see below) and to the ophthalmic artery (supplying the retina — p. 514) accounts for the characteristic combination of *blindness in one eye with contralateral hemiplegia* that may follow stenosis or occlusion of the internal carotid artery. However, occlusion may be 'silent' because of collateral circulation through the arterial circle; the effects are very variable, depending on the state and size of the vessels.

The **posterior cerebral artery** curls back around the cerebral peduncle (supplying it and the optic tract) (Fig. 7.23), and passes back above the tentorium to supply the inferomedial surface of the temporal and occipital lobes (Figs 7.17 and 7.18). Its territory meets that of the anterior cerebral artery at the parieto-occipital sulcus. Its branches extend around the borders of the brain to supply the inferior temporal gyrus and a corresponding strip of cortex on the lateral surface of the occipital lobe. The *visual area* for the opposite field of vision lies wholly within its territory, but it should be noted that the *middle cerebral* branches can sometimes extend sufficiently far back on the occipital lobe to supply the *macular* part of the visual area (p. 640). Thus the macular field of vision may be spared when the rest of the visual area is destroyed by a posterior cerebral thrombosis. The posterior cerebral may receive some or all of its blood from the internal carotid and not the basilar; indeed, this is the primitive embryonic condition where the posterior cerebral is a branch of the carotid. The basilar system is a later development which joins the original posterior cerebral, whose proximal end

usually becomes the posterior communicating. A definitive posterior cerebral arising from the internal carotid is simply a persistence of the embryonic pattern. The *arterial supply of the subcortical nuclei* is by branches from the three cerebral vessels, as might be expected, but there is a fourth which is perhaps unexpected — the anterior choroidal. Branches from the cerebral vessels enter through the perforated substances.

The *anterior perforated substance* receives numerous small branches from the *anterior and middle cerebral arteries*. These are the **striate branches** (long central branches) and are of supreme importance because they supply the *internal capsule*, as well as the thalamus and basal nuclei. Clinicians give them various names such as *perforating*, *lenticulostriate*, *thalamostriate* and *thalamolenticular*, but anatomically they are divided into medial and lateral groups. The *medial striate* branches arise from both the anterior and middle cerebral vessels, and their area of supply includes the *genu* and *posterior limb* of the internal capsule. One of the larger branches from the anterior cerebral is the *recurrent artery* (of Heubner), which supplies the more posterior part of the capsule, including the leg area (but the branch is absent in 3%). The *lateral striate* branches arise from the middle cerebral and anterior choroidal vessels; one of them from the middle cerebral is 'the artery of cerebral haemorrhage' whose rupture or occlusion are the commonest causes of a typical 'stroke' with contralateral hemiplegia.

Branches from the posterior cerebral artery enter the *posterior perforated substance* to reach the thalamus and the caudate nucleus, penetrating the posterior part of the internal capsule on the way.

The **anterior choroidal artery** supplies the choroid plexus, passing below the optic tract to enter the inferior extremity of the choroid fissure at the tip of the inferior horn of the lateral ventricle, just above the uncus. The artery gives branches to the optic chiasma and tract and the lateral geniculate body, and the posterior part of the internal capsule. The plexus receives from the posterior cerebral artery a few additional twigs which enter the choroid fissure behind the thalamus.

Effects of arterial occlusion. Obviously the effect of occlusion of the cerebral arteries will vary with the degree and site of obstruction, but the main effects of complete occlusion may be summarized as follows.

Anterior cerebral: complete contralateral hemiplegia and hemianaesthesia (leg, arm and face), but if distal to Heubner's artery only the opposite leg is affected.

Middle cerebral: complete contralateral hemiplegia and hemianaesthesia (with aphasia if the lesion is left-sided) and cerebral oedema (which may cause hemianopia from compression of the optic radiation).

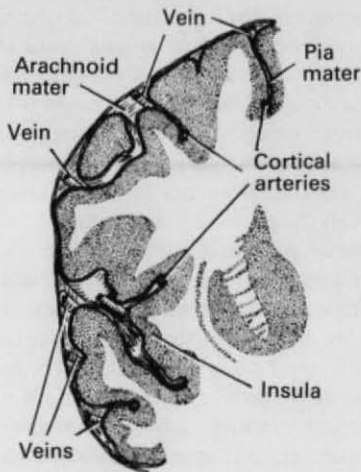


Fig. 7.19 Cortical vessels and meninges of the cerebral hemisphere, in coronal section. Cortical veins adhere to the deep surface of the arachnoid mater where it bridges the sulci. The deep middle cerebral vein lies on the insula, which, being a buried area of cortex, has no arachnoid covering. Over the insula the lateral sulcus is bridged by arachnoid which carries the superficial middle cerebral vein on its deep surface.

Posterior cerebral: contralateral hemianopia and hemianaesthesia, and cerebral oedema.

Anterior choroidal: contralateral hemiplegia, hemianaesthesia and hemianopia.

Cerebral veins

The venous return *does not follow the arterial pattern*. Unlike the cortical arteries, which tend to travel deep in the sulci, the cortical veins tend to travel superficially, in the arachnoid mater (Fig. 7.19). They lie adherent to the deep surface of the arachnoid mater that bridges each sulcus. This helps to keep them open. In general blood flows into the nearest available venous sinus of the dura mater, generally entering obliquely against the bloodstream. Only where there is no sinus near enough (anterior part of the hemisphere and lower parts of basal nuclei) is a venous pattern formed that resembles the arterial pattern.

The superolateral surface of the hemisphere drains into the superior sagittal sinus (Fig. 7.20) by **superior cerebral veins** above and into the transverse sinus below, in each case by veins that enter against the direction of bloodflow. The superior veins, if encountering a blood lake, pass on its cerebral surface beneath the arachnoid (the blood lakes are between the 'two layers' of the dura, Fig. 7.16).

Adherent to the deep surface of the arachnoid mater that bridges the lateral sulcus runs the **superficial middle cerebral vein**, draining the adjacent cortex

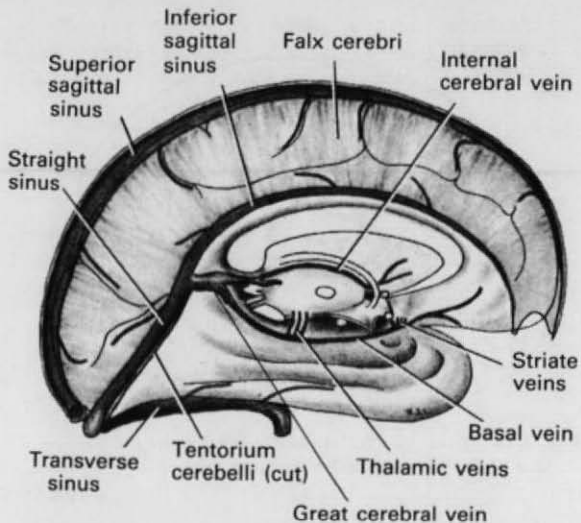


Fig. 7.20 Venous drainage of the cerebral hemisphere, thalamus and basal nuclei, from the medial side. Note that the lower halves of the thalamus and corpus striatum drain via the perforated substances into the basal vein, and their upper halves drain to the internal cerebral vein. Both veins reach the straight sinus.

and emptying into the cavernous sinus. At the posterior end of this vein are *superior and inferior anastomotic veins* which join the superior sagittal and transverse sinuses. The depths of the lateral sulcus and the surface of the insula are too far from a sinus in the dura mater. Blood from this region drains into the **deep middle cerebral vein** which joins the basal vein (see below).

The medial and inferior surfaces of the hemisphere drain by **inferior cerebral veins** into the geometrically nearest venous sinus of the dura mater (the two sagittals and the straight sinus) except anteriorly, where there is no sinus present in the margins of the falx. Here the blood from the surface of the hemisphere is collected into the **anterior cerebral vein**, which returns around the genu of the corpus callosum alongside the anterior cerebral artery to join the basal vein (see below). The anterior cerebral vein drains also the orbital surface of the frontal lobe. It is the only large vein of the brain to have a similar name and course to its companion artery.

At the anterior perforated substance **striate veins** emerge through the perforations. They drain the lower part of the corpus striatum and join the deep middle cerebral vein and the anterior cerebral vein; the veins from these three sources form the **basal vein** (Figs 7.20 and 7.21). This passes around the cerebral peduncle below the optic tract and the anterior choroidal artery, with the fourth nerve and the posterior cerebral artery. It receives veins from the posterior perforated substance; these drain the lower part of the thalamus.

Just below the splenium the two basal veins join the great cerebral vein (see below). Only the lower parts of the basal ganglia drain through the perforated substances into the basal vein; their upper parts drain into the internal cerebral vein.

The **internal cerebral vein** (Fig. 7.21) receives blood from three sources. It is formed at the interventricular foramen by the meeting of the *choroidal vein*, draining the choroid plexus of the lateral ventricle, and the *thalamostriate vein* which lies in the groove between the thalamus and caudate nucleus and receives blood from both. The *veins of the septum pellucidum* which bring blood from the corpus callosum and adjacent cortex and the head of the caudate nucleus (Fig. 7.21) usually join the thalamostriate vein.

The internal cerebral vein so formed runs back in the tela choroidea (double layer of pia mater). It receives

the veins from the tiny choroid plexus of the third ventricle and then joins its fellow to make the **great cerebral vein** (of Galen) just beneath the splenium. This vein is joined by the two basal veins, and with the inferior sagittal sinus it enters the straight sinus.

CEREBRAL STRUCTURE

The **cerebral cortex** is composed of layers of cells which vary in their characteristics in different regions. In general, *motor cortex* has many large *pyramidal cells*, *sensory cortex* has smaller round *granular cells*. All are intermixed with neuroglial cells and their processes and with blood capillaries.

In most parts of the cortex *six layers* of nerve cells can be distinguished, and are conventionally numbered from the surface inwards by Roman numerals. Layer I has an abundance of fibres with relatively few cells, the plexiform layer. Then follow the external granular (II), pyramidal (III), internal granular (IV), ganglionic (V) and multiform (VI) layers, roughly named from the density and shapes of their cells. In layers IV and V there are often prominent strands of horizontal fibres, the *external* and *internal bands of Baillarger*; in the visual cortex the external band is the *stria of Gennari* (p. 587).

Changes in the relative distribution of these layers are most pronounced in the known sensory and motor areas. The postcentral gyrus (touch), the superior temporal gyrus (hearing), and the calcarine sulcus (sight) are covered by cortex in which granular cells predominate, while motor areas typically have larger numbers of pyramidal cells. Among the cells of layer V of the precentral gyrus are the *giant pyramidal cells* (of Betz), which resemble large anterior horn cells of the spinal cord; they give rise to no more than 2% of corticospinal fibres.

The **white matter** is composed of myelinated nerve fibres bound together by the fibres of the neuroglia. Myelin within the central nervous system is derived from the oligodendrocytes (in contrast to the peripheral nervous system where it comes from Schwann cells). The various subcortical masses of grey matter will obviously contain neuronal cell bodies, with different characteristics in each site, but details are reserved for the neurohistological specialist.

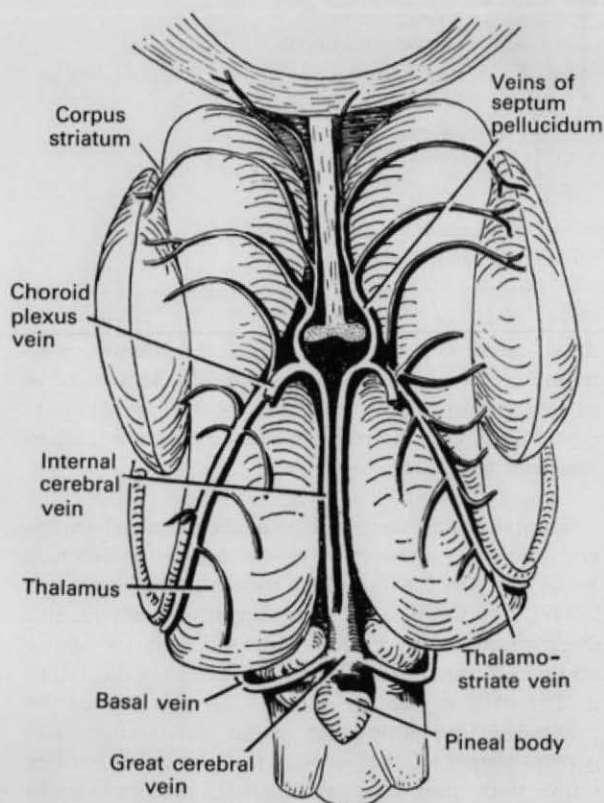


Fig. 7.21 Venous drainage of the thalamus and basal nuclei, from above. The choroidal vein joins the thalamostriate vein at the interventricular foramen to form the internal cerebral vein. Veins of the septum pellucidum drain the upper part of the corpus striatum and enter the internal cerebral vein. The two internal veins run back above the roof of the third ventricle to form the great cerebral vein. This receives each basal vein which brings blood via the anterior and posterior perforated substances from the lower parts of the corpus striatum and thalamus.

PART 2 BRAINSTEM

The **brainstem** is the part of the brain connecting the cerebrum and diencephalon with the spinal cord, and consists of the midbrain, pons and medulla oblongata (Figs 7.3B, 7.6 and 7.22–7.24). It extends from just

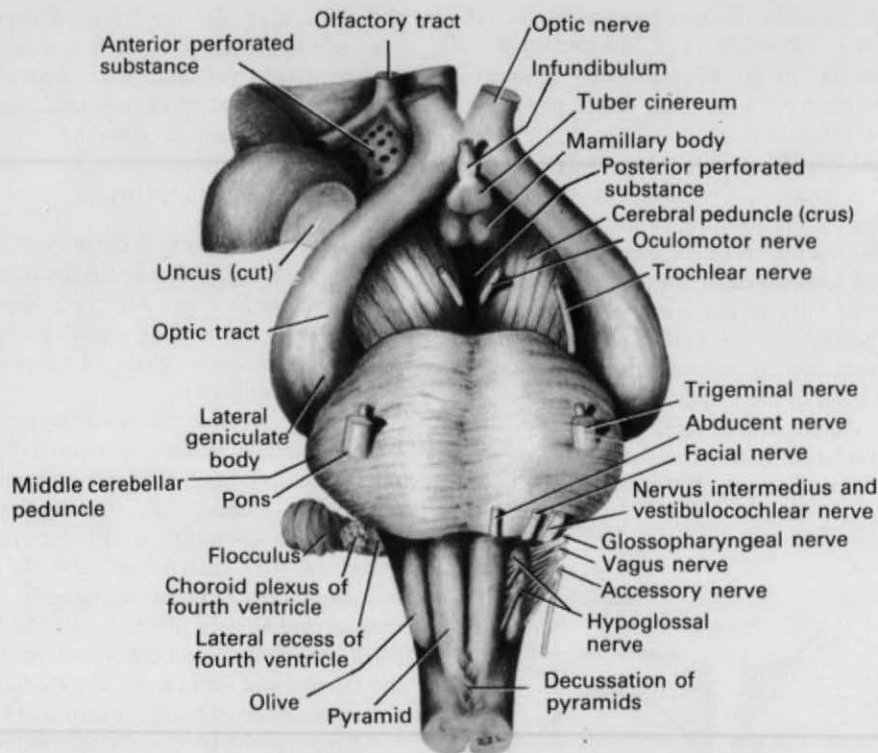


Fig. 7.22 Ventral surface of the brainstem, with all vessels removed. On the left side the cranial nerves are intact; on the right all except the oculomotor and trochlear have been removed.

above the aperture in the tentorium cerebelli to C1 vertebra below the foramen magnum, and the cerebellum projects from its dorsal surface. The medulla oblongata passes through the foramen magnum, and the change of name to spinal cord occurs where the uppermost rootlets of C1 nerve emerge. Do not confuse the medulla oblongata with the spinal medulla, which is the proper name for the spinal cord.

The brainstem consists of fibres and cells. Most of the fibres in the brainstem ascend or descend longitudinally, as in the spinal cord, and most of the cells are aggregated into nuclei (collections of cell bodies). These **nuclei** consist of three groups:

- (1) The nuclei of the third to the twelfth cranial nerves.
- (2) Other named nuclei which are demonstrable, such as the colliculi, the red nucleus, the substantia nigra, the pontine nuclei and the olivary nucleus.
- (3) The reticular formation, a diffuse system of cells and fibres which is intermingled with the named nuclei and tracts, continues into the spinal cord, and is described further on page 611. Some of its cells form

the so-called 'vital centres' — cardiac, respiratory, vaso-motor, etc. — which are not anatomically demonstrable as distinct 'nuclei', but are of great physiological importance. Significant interruption of their function leads to brain death (p. 616).

To understand the positions of the main cell groups and tracts, a minimum of seven sections at different levels is required: two through the midbrain (upper and lower), two through the pons (upper and lower), and three through the medulla (one through the upper and two through the lower parts). They are illustrated in that order in Figures 7.25 to 7.31 which should be referred to frequently when reading this section. The general shapes of the sections and the gross features visible to the naked eye (even without staining) should make each level instantly recognizable, as explained below; stains must be used for more precise definition of cell and fibre groups.

The positions of the main cell groups (nuclei) will be described with the internal structure of each of the three parts of the brainstem; thereafter the longitudinal tracts will be considered in the brainstem as a whole,

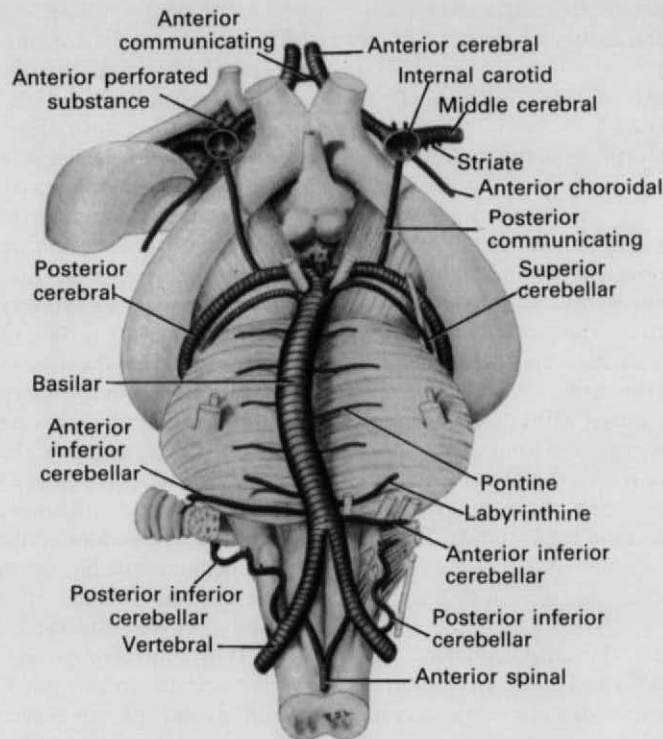


Fig. 7.23 Ventral surface of the brainstem with arteries intact. Although not apparent in a drawing, the arterial circle lies horizontally, at right angles to the basilar artery which is vertical.

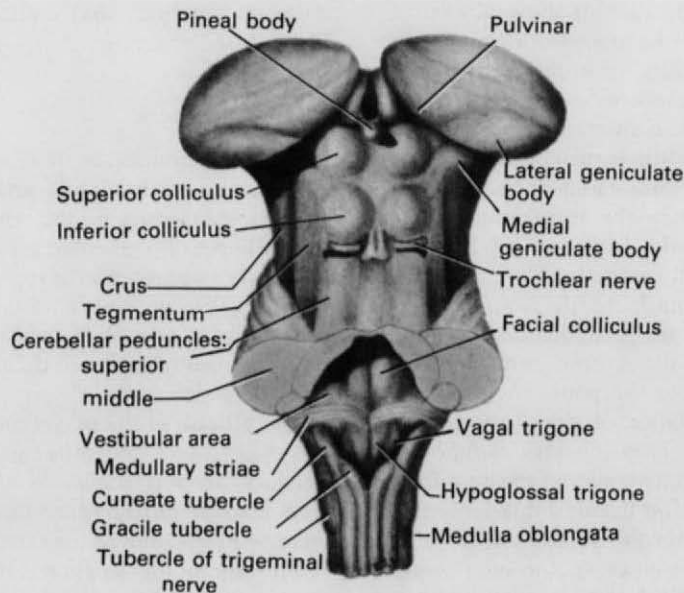


Fig. 7.24 Dorsal surface of the brainstem, after removal of the cerebellum and roof of the fourth ventricle.

since in this way it is easier to appreciate their continuity and changes in position as they course upwards or downwards.

At the outset it is helpful to note the levels of the cranial nerve nuclei as follows:

Those of the third and fourth are in the midbrain.

The motor nucleus of the fifth, and the sixth and seventh, are in the pons. The three sensory nuclei of the fifth are in the midbrain, pons and medulla.

The eighth nerve nuclei overlap the junction of pons and medulla and lie partly in each.

The nuclei of the ninth to the twelfth are in the medulla (with the eleventh having a spinal part derived from the cervical region of the cord).

The arrangement of the nuclei within the brainstem is not random, as might be suspected from casual study of brainstem sections; there is a logical pattern which is best understood by considering their development (p. 627) after their positions have been studied.

MIDBRAIN

The **midbrain** connects the diencephalon and cerebrum to the pons (Figs 7.4 and 7.22). In relation to the skull it extends from a level just above the dorsum sellae of the sphenoid to a line that joins the apices of the petrous parts of the temporal bones, i.e. most of it lies in the posterior cranial fossa, with its upper part passing through the tentorial notch, and the front part of the cerebellum lying behind. The pineal body, with the splenium of the corpus callosum above it, overlies the superior colliculi on the dorsal surface of the midbrain. Above and behind this lies the inferior surface of the cerebral hemisphere.

The midbrain consists of right and left halves, each half forming a **cerebral peduncle** made up of a ventral part, the *base* (basis pedunculi) and a dorsal part, the *tegmentum*. Running through the tegmentum is the **aqueduct of the midbrain** (aqueduct of Sylvius), joining the third and fourth ventricles. The part of the tegmentum dorsal to the aqueduct is the *tectum*.

On the *ventral surface* are seen the bases of the peduncles (often called the *crura*), which lie in V-shaped manner cranial to the pons, enclosing the posterior perforated substance of the diencephalon between them (Fig. 7.22). They converge as rope-like bands down towards the upper border of the pons from their point of emergence below the thalamus.

Dorsally the midbrain is roughly cylindrical. It shows two pairs of low rounded eminences, the *superior* and *inferior colliculi* (formerly called corpora quadrigemina, Fig. 7.24). The superior colliculi lie below the pineal body, behind the posterior ends of the thalami and the

roof of the third ventricle, and are overlapped somewhat by the splenium of the corpus callosum. Lateral to each superior colliculus is the *medial geniculate body* which, although appearing to belong to the brainstem, is part of the thalamus (p. 596). Below the inferior colliculi the *superior cerebellar peduncles* converge into the dorsal surface of the midbrain from the cerebellum.

The third and fourth cranial nerves leave the brainstem at the midbrain, but the sites of their emergence are very different (Figs 7.22 and 7.23). The **oculomotor nerve** leaves through the *medial* surface of the crus, on the ventral surface of the midbrain, and passes forwards between the posterior cerebral and superior cerebellar arteries in the interpeduncular cistern to reach the roof of the cavernous sinus. The **trochlear nerve** leaves the *dorsal* surface of the midbrain just behind the inferior colliculus. This nerve is unique in three respects: it is the smallest cranial nerve, the only one to emerge from the dorsal surface of the brainstem, and the only one to decussate within the brainstem. The nerve curls round the *lateral* side of the peduncle and passes forwards between the same two arteries as the third nerve (posterior cerebral and superior cerebellar) but farther laterally, to run just below the free edge of the tentorium and enter the cavernous sinus where the free and attached margins of the tentorium cross (p. 567).

The **optic tract** also curls round the peduncle; ventral to the tract are the *basal vein* on its way from the anterior perforated substance to the great cerebral vein (p. 603) and the *posterior communicating artery* join the posterior cerebral and internal carotid arteries (Fig. 7.23).

Internal structure

Sections of the midbrain are recognized by the colliculi of the tectum on the dorsal surface, the aqueduct, and the rectangular crura on the ventral surface, delimited by a dark line of pigmented cells, the substantia nigra. Other naked-eye features at superior colliculus level are the red nucleus with fibres of the third nerve probably seen sweeping through it, while at inferior colliculus level is the centrally-placed decussation of the superior cerebellar peduncles.

The **colliculi** of the *tectum* contain reflex centres for light and sound and the grey matter round the aqueduct contains the *nuclei* of the *third* and *fourth* nerves and the *mesencephalic nucleus* of the *fifth* nerve. The *tegmentum* contains the *red nucleus*.

Although in the midbrain at the junction of the tegmentum and crus, the **substantia nigra** belongs functionally to the basal nuclei (p. 581). Many of its cells contain melatonin, responsible for its naked-eye

dark appearance. Some of its cells give rise to *nigrostriatal fibres* which are dopaminergic and project back to the caudate nucleus and putamen. The loss of about 80% of its dopaminergic cells is the fundamental defect in parkinsonism.

The **superior colliculus** contains cells involved in *general light reflexes*, while the **inferior colliculus** is concerned with *sound reflexes*. They receive inputs from the retina and cochlea respectively and project to the motor nuclei of cranial and spinal nerves (via tectobulbar and tectospinal tracts) for reflex movements of the eyes, head, body and limbs away from or towards light and sound stimuli. The above *general light reflexes* must not be confused with the *pupillary light reflexes* (p. 518) involving the **pretectal nuclei**, which lie just cranial to the superior colliculi at the junction of the midbrain and diencephalon (Fig. 7.38).

The **oculomotor nucleus** lies close against the midline ventral to the aqueduct (Fig. 7.25), in line with the other somatic motor nuclei (fourth, sixth and twelfth). The parasympathetic part (**Edinger-Westphal** or accessory oculomotor nucleus) lies near the midline in the cranial part of the nucleus; its axons run out with the third nerve and relay in the ciliary ganglion, from which postganglionic fibres innervate the sphincter pupillae and ciliary muscles (p. 518). The third nerve passes ventrally through the red nucleus to emerge from the brainstem on the *medial* side of the base of the peduncle.

The **trochlear nucleus** lies caudal to the oculomotor nucleus, ventral to the aqueduct at inferior colliculus level (Fig. 7.26). The nerve proceeds dorsally and crosses the midline, where it decussates with its fellow dorsal to the aqueduct. It emerges through the superior medullary velum behind the inferior colliculus (Fig. 7.24).

The **red nucleus** lies in the tegmentum just ventral to the third nerve nucleus, the axons of which pass through it (Fig. 7.25). It is easily made out in sections of the midbrain, being slightly larger than a full-sized pea. It receives fibres coming from the dentate nucleus in the opposite cerebellar hemisphere via the superior cerebellar peduncle. It has many other connexions, especially with the cortex and globus pallidus. Its efferent fibres decussate at the level of the inferior colliculi and descend to the pontine nuclei and spinal cord. The *rubrospinal tract* is part of the extrapyramidal system (p. 623). Despite its size the red nucleus seems to be of little functional significance in man, and it is not associated with any known disease.

The **medial geniculate body**, which is applied to the dorsal surface of the midbrain at the level of the superior colliculus (Fig. 7.25), belongs to the thalamus and has been described on page 596.

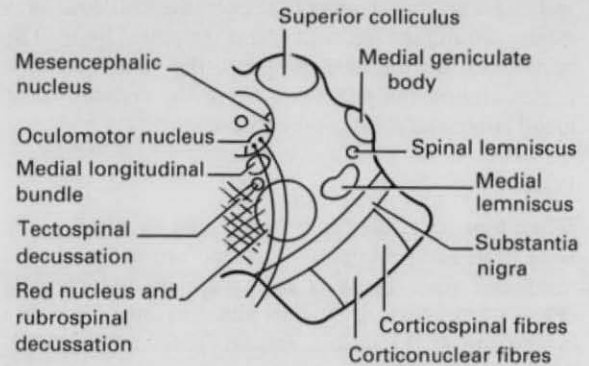


Fig. 7.25 Cross-section of the midbrain at the level of the superior colliculi.

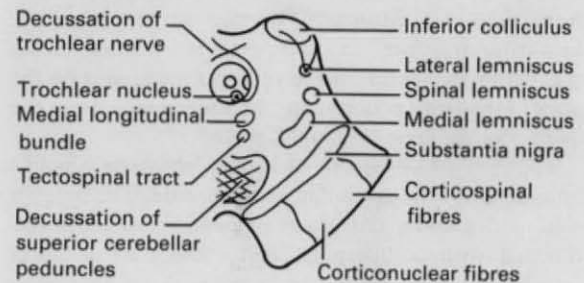


Fig. 7.26 Cross-section of the midbrain at the level of the inferior colliculi.

The **mesencephalic nucleus** of the trigeminal nerve lies in the central grey matter, lateral to the aqueduct, throughout the whole length of the midbrain. This long slender nucleus receives proprioceptive fibres from the muscles supplied by the mandibular branch of the trigeminal (muscles of mastication) and from the muscles of the orbit and face and, perhaps, the muscles of the tongue (see p. 482). It is unique in being a collection of first neuron cells buried in the central nervous system (p. 622).

Between the medial lemniscus and the central grey matter the tegmentum contains fragments of grey matter broken up by criss-cross bundles of white fibres. The 'network' appearance so produced gives it the name **reticular formation**. It is traceable through the pons (p. 609) and medulla into the upper spinal cord, and is described further on page 611.

Blood supply

The midbrain is supplied by the *posterior cerebral* and *superior cerebellar arteries* as they curl around the cerebral peduncle. Medial and lateral central branches enter the crura to supply the substantia nigra and red nucleus

and, on the dorsal aspect, supply the colliculi, grey matter around the aqueduct, and the pineal body. The veins drain for the most part into the basal vein as it passes around the peduncle. From the colliculi some blood enters the great cerebral vein.

PONS

When looking at the brain from below (ventrally), the pons is an easily recognized central feature — a broad transverse mass between the midbrain and medulla (Fig. 7.22), curving at the sides to sink into the cerebellum as the *middle cerebellar peduncle* (Fig. 7.6). The only cranial nerve to emerge from the pons, the fifth, does so by a large sensory and small motor root; their point of emergence marks the change of name from pons to peduncle. The two nerve roots pass forwards together in the *posterior* cranial fossa (i.e. below the tentorium) to run over the groove on the apex of the petrous bone into the trigeminal cave in the *middle* cranial fossa (Fig. 6.94, p. 566).

The *ventral surface* of the pons shows a shallow midline groove with a bulge on either side. The bulge is due to the underlying mass of pontine nuclei, intermingled with corticospinal and corticonuclear fibres (see below). This ventral surface lies along the clivus, separated from the bone by the subarachnoid pontine cistern, in which the basilar artery runs upwards. The artery may or may not lie in the midline groove; usually it has a gentle curve to one side. The superior cerebellar artery curls round the upper margin of the pons. The labyrinthine artery passes laterally to reach the internal acoustic meatus. The sixth nerve runs upwards across the ventral surface to enter the dura on the clivus, while the seventh and eighth emerge more laterally at the junction of pons and medulla. Most laterally the flocculus of the cerebellum and the choroid plexus that has emerged from the lateral recess of the fourth ventricle lie beside its lower border, in the cerebello-pontine angle (Fig. 7.22).

The *dorsal surface* of the pons is concealed by the attached cerebellum. The aqueduct of the midbrain opens out at the upper border of the pons into the cavity of the fourth ventricle, which is mostly pontine but medullary at its lower end (p. 610). The pontine part of the roof of the ventricle consists only of a thin sheet of white matter, the superior medullary velum (Fig. 7.24), upon which lies the lingula of the cerebellum. The velum is attached at each side to the superior cerebellar peduncles.

Internal structure

Sections of the pons are recognized by the mass of cells

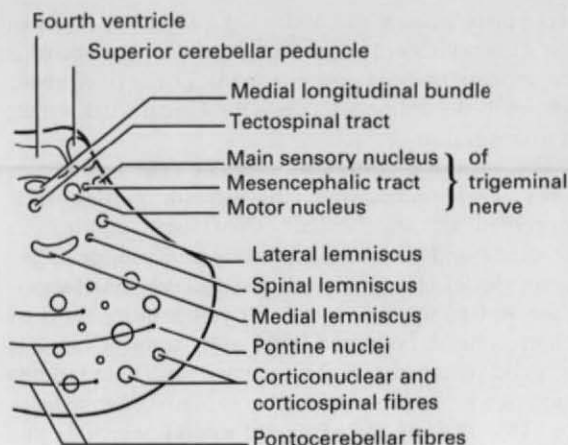


Fig. 7.27 Cross-section of the upper pons.

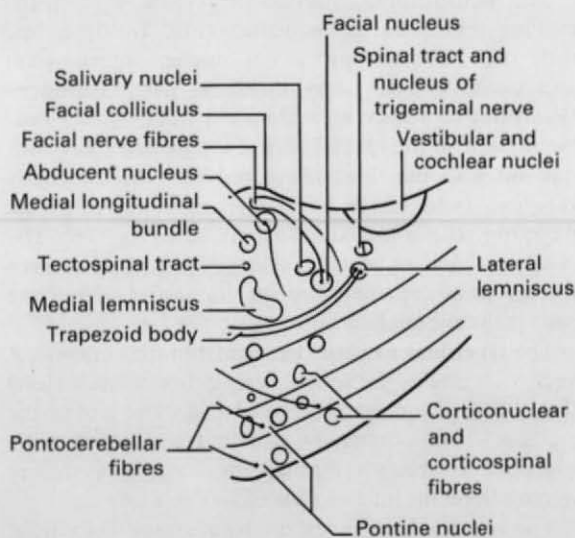


Fig. 7.28 Cross-section of the lower pons.

and fibres occupying the large ventral part (Figs 7.27 and 7.28), quite distinct in shape from the rather rectangular crura of the midbrain peduncles (Figs 7.25 and 7.26) and the bulges of the medulla (Figs 7.29–7.31). The dorsal feature in the upper pons is the almost rectangular but closed cavity of the *fourth ventricle*; sections of the lower pons, which contains the widest part of the floor of the fourth ventricle, are usually presented as a broad band (without any ventricular roof) with cut edges at each side (the transected middle cerebellar peduncles).

In the ventral part the cells are the **pontine nuclei**, from which fibres emerge to cross to the opposite side and form the middle cerebellar peduncle. With the

various corticopontine fibres that have travelled down in the cerebral peduncles to synapse with the pontine nuclei, they complete an extensive corticopontocerebellar pathway.

In the dorsal part of the pons are the nuclei of the fifth to eighth nerves and the salivary nuclei.

The **motor nucleus of the trigeminal nerve** is in the upper pons below the lateral part of the floor of the fourth ventricle. The fibres pass ventrally and laterally to emerge as already noted as a small *motor root* at the junction of the pons and the middle cerebellar peduncle.

Lateral to the motor nucleus is the **main sensory nucleus of the trigeminal nerve**. It receives those incoming fibres of the *sensory root* subserving touch. Its caudal continuation into the lower pons (and medulla) is the **spinal nucleus**, which receives pain and temperature fibres, while its upward continuation is largely a small bundle of fibres but with some cell bodies, the mesencephalic tract of the trigeminal, leading to the mesencephalic nucleus (p. 607) for proprioception.

In the lower part of the pons the **abducent nucleus** lies near the midline just below the floor of the fourth ventricle, but with fibres of the facial nerve overlying it. The abducent nucleus plus the overlying facial nerve fibres form a small swelling, the *facial colliculus*, in the ventricular floor (Fig. 7.24). The **facial nucleus** itself lies deeper and farther from the midline; note therefore that the *facial nucleus* is *not* responsible for the *facial colliculus*.

A collection of cells alongside the facial nucleus forms the **superior salivary nucleus** (parasympathetic). It provides axons which pass out in the nervus intermedius part of the facial nerve and reach the pterygopalatine and submandibular ganglia. The lower part forms the **inferior salivary nucleus**, just above the pontomedullary junction; its fibres join the glossopharyngeal nerve to reach the otic ganglion.

The **nuclei of the vestibulocochlear nerve** lie beneath the floor of the lateral angle of the fourth ventricle (the *vestibular area*) in both the pons and medulla; vestibular and cochlear nuclei are separate. The vestibular fibres that emerge from the internal acoustic meatus pass anterior to the inferior cerebellar peduncle of the medulla and synapse in the **vestibular nuclei**, many of whose fibres pass back into that peduncle. Other fibres join the medial longitudinal bundle and connect with extraocular nuclei and cervical anterior horn cells. Some of these connexions provide the basis for the vestibulo-ocular reflexes (p. 515).

The **cochlear nuclei** are mainly medullary but extend into the lower pons. They receive fibres from the

spiral ganglia of the cochlea and send their axons to dorsal and ventral cochlear nuclei. Axons from these form the decussating *trapezoid body* (p. 637), part of the auditory pathway.

The very uppermost ends of the *dorsal nucleus of the vagus* and the *nucleus of the tractus solitarius* also extend into the pons but essentially belong to the medulla, where they are described.

The pontine part of the **reticular formation** (p. 611) lies dorsal to the pontine nuclei and their intermingled fibres.

Blood supply

The pons is supplied mainly by *pontine branches* from the *basilar artery*, with contributions from the superior cerebellar and anterior inferior cerebellar vessels. Venous return is into the inferior petrosal sinuses and the basilar plexus.

MEDULLA OBLONGATA

The **medulla oblongata** extends between the pons and spinal cord. It lies almost vertically from a line joining the jugular tubercles of the occipital bone to the atlas, thus passing through the foramen magnum. It is embraced dorsally by the convex cerebellar hemispheres and lies in the deep groove between them, the *vallecula* of the cerebellum. The lower end which contains the upward continuation of the central canal of the spinal cord is commonly called the 'closed part of the medulla', while the upper end, where the canal comes to the surface as the lower part of the floor of the fourth ventricle, is the 'open part'.

Ventrally (Fig. 7.22) the upper part of the medulla is deeply grooved in the midline, with a bold convexity on either side, the **pyramid**, due to the contained corticospinal fibres. Lateral to the pyramid is another convexity, the **olive**, due to the underlying inferior olivary nucleus. Lateral to the olive the lateral surface of the medulla is formed by the *inferior cerebellar peduncle*, which enters the cerebellum medial to and below the middle peduncle.

The last seven cranial nerves all have attachments related to the medulla. The sixth nerve emerges between the pons and the pyramid, with the main part of the seventh nerve between the pons and the olive, and the nervus intermedius part of the seventh and the eighth nerve at the junction of the pons and the inferior cerebellar peduncle. The rootlets of the ninth, tenth and cranial part of the eleventh nerves emerge lateral to the olive, and those of the twelfth by two small groups of rootlets between the pyramid and the olive.

Dorsally the lower part of the floor of the fourth ventricle forms the upper part of the medulla (Fig. 7.24). Here the roof of the ventricle is ependyma and pia mater (p. 613). At the lower corner of the diamond-shaped floor the *hyoglossal trigone* is adjacent to the midline, with the *vagal trigone* lateral to it. Higher up and at the lateral corners of the diamond is the vestibular area and the medullary striae (p. 614).

In the lower or *closed part* of the medulla, the fourth ventricle has become narrowed to the tiny *central canal*, and the external dorsal surface shows small elevations, the *gracile* and *cuneate tubercles*, and the usually less well-defined *trigeminal tubercle*.

Internal structure

The naked-eye appearance of a section through the upper part of the medulla is instantly recognizable by the bulges of the pyramid and olive and the sac-like olivary nucleus (Fig. 7.29). The lower medulla still has the pyramids ventrally, but now there are gracile and cuneate tubercles dorsally. Visible decussation of the pyramids characterizes the lowest part of the medulla, and at a slightly higher level is seen the central decussation of the fibres forming the medial lemnisci (Figs 7.30 and 7.31).

Most of the nuclei of the medulla are below the floor of the fourth ventricle. The hyoglossal nucleus underlies the hyoglossal trigone and the dorsal nucleus of the vagus is under the vagal trigone; more laterally are the nucleus of the tractus solitarius and the spinal nucleus and tract of the trigeminal nerve, with the vestibular and cochlear nuclei at the dorsal edge. At a deeper level is the nucleus ambiguus, with the inferior olivary nucleus ventrally.

The **hypoglossal nucleus** adjacent to the midline gives rise to the hypoglossal nerve fibres which pass ventrally to emerge between the pyramid and olive.

The **dorsal nucleus of the vagus** contains motor cell bodies for cardiac and visceral muscle and the cells of secretomotor fibres for glands (in particular those of the stomach). Although the nucleus in the past has been considered to be a mixed nucleus with afferent cell bodies as well as motor, recent investigators believe that the sensory cells properly belong to the **nucleus of the tractus solitarius**. Afferent fibres form the *tract* which is almost surrounded by cells of the *nucleus*. The nuclei of the two sides meet in the lowest part of the open medulla, so they appear jointly as a V-shaped collection of cells as viewed dorsally. The cells are the most tightly packed of any brainstem nucleus. Its upper part receives taste fibres from the chorda tympani (nervus intermedius part of the facial nerve), lingual branch of the glossopharyngeal nerve and internal laryngeal

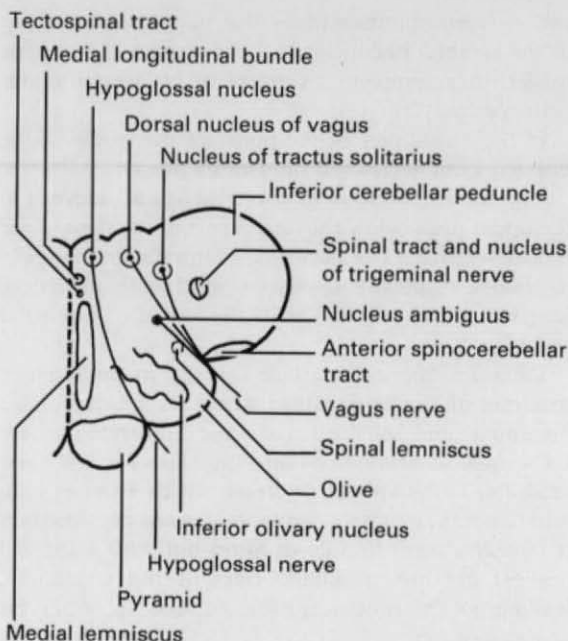


Fig. 7.29 Cross-section of the open part of the medulla.

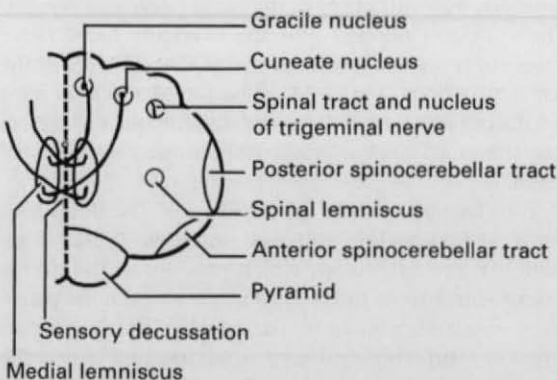


Fig. 7.30 Cross-section of the upper part of the closed medulla.

branch of the vagus. The rest of the nucleus receives many afferent fibres of the glossopharyngeal and vagus nerves from thoracic and abdominal viscera, including those from the baroreceptors and chemoreceptors of the carotid sinus and carotid body and the aortic arch and aortic bodies (p. 438 and 256). It has extensive connexions with the dorsal nucleus of the vagus and the reticular formation, and is an important component of the pathways for the cough (p. 503) sneeze (p. 473), gag (p. 496) and vomiting (p. 334) reflexes. Some of its cells form the inspiratory centre (p. 253).

The **nucleus ambiguus** contains motor cell bodies

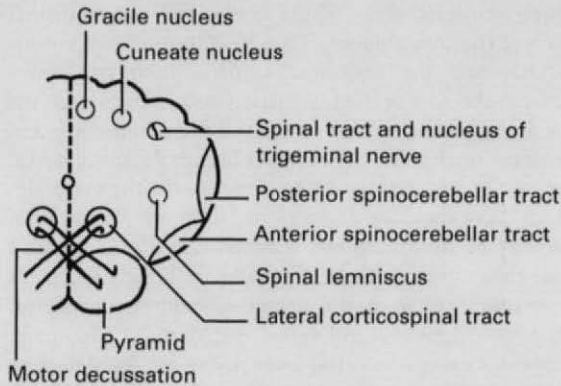


Fig. 7.31 Cross-section of the lower part of the closed medulla.

for the skeletal muscle of the larynx, soft palate, pharynx and upper oesophagus, all distributed by branches of the vagus except for the supply to stylopharyngeus which is by the glossopharyngeal nerve. The cells of the upper part of the nucleus send their fibres to the palate, those of the middle part reach the pharynx and oesophagus, while those from the lowest part supply the larynx.

Fibres from the dorsal vagal nucleus are joined by those from the nucleus ambiguus and the nucleus of the tractus solitarius, contributing to the glossopharyngeal, vagal and accessory nerve rootlets emerging lateral to the olive.

The **spinal nucleus (and tract) of the trigeminal nerve** continues down into the medulla from the pons (p. 609) and lies lateral to the nucleus of the tractus solitarius.

The **inferior olivary nucleus** is a crenated C-shaped lamina of grey matter, in section like a wrinkled sac with an open end facing towards the opposite inferior cerebellar peduncle. Its fibres (*olivocerebellar*) decussate across the midline to enter this peduncle (p. 619).

The **cochlear and vestibular nuclei** extend into the medullary part of the floor of the fourth ventricle, and have been considered with the pons (see above).

The **gracile and cuneate nuclei** underlie the corresponding tubercles of the dorsal surface of the lower medulla. They contain the cell bodies on which the incoming fibres of the gracile and cuneate tracts of the spinal cord terminate, and the nuclei give origin to the *medial lemniscus* (p. 613). Some cuneate cells constitute the *accessory cuneate nucleus*, whose fibres (*cuneocerebellar*) convey proprioceptive impulses from the upper limb to the cerebellum (via the inferior peduncle), instead of by the usual pathway for such impulses in the spinocerebellar tracts.

The medullary **reticular formation**, continuous upwards with that of the pons and downwards into the spinal cord at the lateral margin of the central grey matter, is the irregular mass of cells and fibres occupying much of the area between the inferior olivary nucleus and the floor of the fourth ventricle, intermingled with other cell groups and tracts. Certain cells of the reticular formation, in the region of the vagal nucleus and tractus solitarius, constitute the cardiac, respiratory and vasomotor centres, often collectively known in the past as the 'vital centres'. They are not anatomically demonstrable as distinct nuclei, but major disturbances of this area result in death (p. 616), which seems adequate reason to call them vital centres in spite of the current fashion to drop the term.

On the medial side of each gracile nucleus, as they diverge from one another at the lower angle of the ventricle, is the small *area postrema*, the site of the *vomiting centre* and the *chemoreceptor trigger zone*, whose cells communicate with the cardiac and respiratory centres. It is one of the few regions with no blood/brain barrier (p. 600) and so can be affected by elements in the bloodstream, e.g. apomorphine to induce vomiting.

Although anatomically such a diffuse entity, the brainstem reticular formation is of great physiological significance, being responsible for the 'alert' or 'wakeful' component of consciousness. It plays a part in the control of many other functions, including motor activity (as part of the extrapyramidal system), sensory function (by modifying sensory input to the thalamus), autonomic activity (via the medullary vital centres) and circadian rhythms and endocrine secretion (via the hypothalamus). Among its many specific connexions are those from the cerebral cortex of the same side via the corpus striatum and globus pallidus (p. 581), from the opposite cerebellar hemisphere via the dentate nucleus (p. 618), and from the hypothalamus and other components of the limbic system (p. 588). Some reticular formation cells give origin to the reticulospinal tracts (p. 613) which are part of the extrapyramidal system, and others receive spinoreticular fibres which are part of the pain pathway from the spinal cord (p. 624). Further cells provide important communications between cranial nerve nuclei, e.g. for eye movements, the corneal reflex, swallowing, etc.

Blood supply

The medulla is supplied ventrally by branches of the *vertebral* and *basilar arteries*, and laterally and dorsally by the *posterior inferior cerebellar artery* (Fig. 7.23). The *anterior spinal* branch of the vertebral gives penetrating branches which supply the region next to the midline, i.e.

the part containing the pyramid, medial lemniscus and hypoglossal nucleus. Damage to these vessels produces the *medial medullary syndrome* — paralysis of the tongue on the same side and hemiplegia with loss of touch and kinaesthetic sense on the opposite side. Damage to the vessels of the lateral and dorsal part gives rise to the *lateral medullary syndrome* or 'syndrome of the posterior inferior cerebellar artery'. The loss of nucleus ambiguus function paralyses the vocal fold and palatal and pharyngeal muscles on that side, giving dysphonia and dysphagia. Loss of the uncrossed spinal tract of the trigeminal and of the crossed spinal lemniscus results in loss of pain and temperature sensation on the same side of the face and opposite side of the body. There will also be a Horner's syndrome (p. 519) on the ipsilateral side due to interruption of the descending sympathetic pathway. Involvement of the vestibular nuclei causes vertigo and nystagmus with nausea and vomiting.

The *veins* drain dorsally to the occipital sinus and ventrally into the basilar plexus of veins and the inferior petrosal sinus. The medullary veins communicate with the spinal veins.

BRAINSTEM TRACTS

Some tracts in the brainstem begin from cell groups therein, but most are passing through from the rest of the brain to the spinal cord or vice versa. The most important of the long *descending tracts* are the corticonuclear and corticospinal fibres concerned with voluntary movement, supplemented for posture and co-ordination of movement by reticulospinal and vestibulospinal tracts which begin in the brainstem. The main *ascending tracts* are the medial lemniscus for touch and associated sensations, beginning in the medulla, and the spinal lemniscus and spinoreticulothalamic fibres for pain and temperature, beginning in the cord and brainstem respectively. While reading the descriptions of these and other tracts, frequent reference should again be made to the brainstem sections in Figures 7.25 to 7.31.

Descending tracts

Cells in layer 5 of the sensorimotor area M_{SI} (p. 586) give rise to **corticospinal** and **corticonuclear fibres**, by clinical convention often collectively called *pyramidal* (though some authorities confine this term to corticospinal fibres, which pass through the pyramid of the medulla, hence the name. Corticonuclear fibres were formerly called *corticobulbar*; bulb was an old name for the lower brainstem). However, only 40% of all these fibres come from this motor area (though they appear to be the ones that matter most); the remainder come from

widely scattered areas of the cortex and not just other parts of the frontal lobes. They pass through the corona radiata, and the *corticonuclear fibres* then run down through the *genu* of the internal capsule (p. 583) into the brainstem. Some will go straight to the oculomotor and trochlear nuclei, and the others collect in the most medial part of the central three-fifths of the crus of the midbrain. From there they run down to reach the motor nuclei of the rest of the brainstem. Cranial nerve nuclei which send their fibres to skeletal muscle are mostly *bilaterally innervated* (i.e. from the cortex of both hemispheres, although there are individual variations). The most important exception is the *lower part of the facial nucleus*, which is only supplied by the *opposite* cortex (p. 641).

The *corticospinal fibres* lie in the anterior two-thirds of the posterior limb of the internal capsule (p. 583). Continuing down to the brainstem, they occupy the central and lateral parts of the central three-fifths of the crus of the midbrain peduncle, with the 'arm' fibres medial to the 'leg' fibres. In the pons the fibres become broken up into small bundles among the pontine nuclei; in longitudinal sections they form naked-eye white strands. Passing on to the medulla the bundles collect into a single large mass forming the bulging **pyramid** adjacent to the midline. Each pyramid contains about 1 million nerve fibres of which 700 000 are small and myelinated (1–4 μ m diameter). In the lowest part of the medulla 85% of the fibres cross to the opposite side in the **motor decussation** (decussation of the pyramids) to form the *lateral corticospinal tract* of the cord (p. 625). Some of the decussating fibres may be seen on the surface. The few uncrossed fibres continue downwards as the *anterior corticospinal tract*, but they also eventually cross in the spinal cord, where all fibres end in the anterior horn (p. 621).

After arising from many areas of all four lobes of the cortex, **corticopontine fibres** pass through all parts of the internal capsule to the crus of the midbrain peduncle. Frontopontine fibres occupy the medial one-fifth and temporo-, parieto-, and occipitopontine fibres occupy the lateral one-fifth. All end by synapsing with cells of the *pontine nuclei* (p. 608) whose axons *decussate* to form the *pontocerebellar fibres* of the middle cerebellar peduncle. This is one of the pathways by which the cerebral cortex communicates with the cerebellar cortex.

The **superior cerebellar peduncles** (p. 619) enter the midbrain tegmentum and decussate at the level of the inferior colliculi on their way to the red nuclei (at superior colliculus level), whose efferent fibres form the **rubrospinal tracts** which immediately decussate (in the *ventral tegmental decussation*) before passing downwards. Just dorsal is the smaller *dorsal tegmental decussation*, formed by the crossing of the **tectospinal tracts**.

The **medial longitudinal bundle** lies immediately ventral to the grey matter round the aqueduct, and remains adjacent to the midline at lower levels. It extends from the upper border to the midbrain to the upper cervical part of the spinal cord. It links the vestibular nuclei with a number of motor nuclei, in particular the third, fourth and sixth, to help co-ordinate audiovisual reflexes and movements of the eyes, head and neck (with which the small tectospinal and rubrospinal tracts assist; they descend no farther than the cervical region of the cord).

The **lateral** and **anterior reticulospinal tracts** arise from the medullary and pontine parts of the reticular formation respectively. They are rather ill-defined in the brainstem, and their fibres become largely mixed with corticospinal fibres in the spinal cord. The **lateral vestibulospinal tract** originates from the lateral vestibular nucleus and soon enters the cord, where all these extrapyramidal tracts end in the anterior horn (p. 621).

The **descending sympathetic tract** from the hypothalamus and probably other higher centres is also ill-defined. Its fibres run in the region of the spinal lemniscus, and they end in the thoracolumbar lateral horn (p. 621).

Ascending tracts

The **medial lemniscus**, the main ascending pathway of the brainstem for touch and its associated sensations (p. 623), begins in the lower medulla, formed by the axons of the *gracile* and *cuneate nuclei* of the opposite side which have crossed (as *internal arcuate fibres*) in the **sensory decussation**. At first the medial lemniscus lies longitudinally adjacent to the midline, but as it passes up through the pons and midbrain it deviates laterally before reaching the thalamus. On its upward path it is joined by the **trigeminal lemniscus**, fibres from the main sensory and spinal nuclei of the trigeminal nerve.

The **spinal lemniscus** is the upward continuation of the lateral spinothalamic (anterolateral) tract of the cord (pain and temperature, p. 624). It lies near the middle of the lateral part of the medulla, and runs up the brainstem at the lateral and then the dorsal edge of the medial lemniscus. It quickly becomes very much smaller, since most of its fibres end in the reticular formation rather than continuing all the way to the thalamus (p. 624).

The **lateral lemniscus** is formed by the upgoing fibres of the *trapezoid body*, the name given to transversely decussating fibres from the cochlear nuclei at the pontomedullary junction. This lemniscus termi-

nates on cells of the inferior colliculus and medial geniculate body for auditory reflexes. Other fibres from the medial geniculate body pass to the auditory area of the cerebral cortex. Both the trapezoid body and lateral lemniscus contain cell stations which make connexions with the extraocular nuclei via the medial longitudinal bundle.

The **spinal tract of the trigeminal nerve** consists of incoming pain and temperature fibres from the trigeminal nerve. Perhaps surprisingly, they pass *down* the brainstem before synapsing with the cells forming the *spinal nucleus* of the trigeminal, from which axons run up to join the medial lemniscus (see above).

The **anterior** and **posterior spinocerebellar tracts** lie at the lateral margin of the lower medulla. The posterior tract enters the inferior cerebellar peduncle but the anterior tract continues up the lateral part of the brainstem to enter the superior peduncle.

FOURTH VENTRICLE

The substance of the midbrain surrounds the aqueduct and the substance of the lower medulla surrounds the central canal. However, between the two, the substance of pons and upper medulla lies ventral and the central canal is expanded into a cavity, the **fourth ventricle**, which is roofed in by little more than ependyma and pia mater (Fig. 7.6).

The **roof** is updrawn into a tent shape (the ridge-pole of the tent lying transversely) and is covered by the cerebellum. The *upper part* of the roof lies over the pons. The ependyma here is covered with a thin sheet of white matter, the *superior medullary velum*, which is bounded by the superior cerebellar peduncles (Fig. 7.24). The *lower part* of the roof lies over the medulla. The ependyma is covered in its upper part by the inferior medullary velum, a thin sheet of white matter from the base of the flocculus, but in the lower part ependyma and pia mater alone form the roof. The lower margin of the roof is attached to the margins of the gracile and cuneate tubercles and is perforated by a midline slit, the **median aperture** (foramen of Magendie), by which cerebrospinal fluid escapes into the cerebellomedullary cistern.

The cavity is prolonged laterally as a narrow **lateral recess** around and behind the inferior cerebellar peduncle; here the roof is attached to the margins of the medullary striae (see below). The narrow, tubular lateral recess has a patent extremity, the **lateral aperture** (foramen of Luschka), which opens anteriorly, just behind the eighth nerve, into the pontine cistern (Fig. 7.22). Through these three apertures (one median and two lateral) the cerebrospinal fluid escapes

from the ventricular system into the subarachnoid space for absorption by the arachnoid villi. These are the only exits from the system; if blocked, e.g. following meningitis, the result is *hydrocephalus*. The extent of the lateral recess is indicated by the cast in Figure 7.9.

The **choroid plexus** of the fourth ventricle is a small bilateral L-shaped structure which indents the medullary part of the roof. It commences at the lateral aperture by a branch of the posterior inferior cerebellar artery. Here it lies just below the flocculus. It indents the roof of the lateral recess, passes medially to meet its fellow, and the two turn down towards the median aperture. Together they form a T-shaped plexus, with the central stem being double. The veins from the plexus drain back into the occipital sinus.

The **floor** of the fourth ventricle is diamond shaped and properly known as the *rhomboid fossa* (Fig. 7.24). The upper boundaries are the superior cerebellar peduncles, the lower are formed by the gracile and cuneate tubercles and their underlying nuclei and, above them, by the inferior cerebellar peduncles. A midline groove, the *median sulcus*, runs from the aperture of the aqueduct of the midbrain above to the commencement of the central canal below. On each side of the groove the floor is symmetrical. At its widest part the floor is crossed transversely by glistening white fibres, the *medullary striae*. They lie between pontine and medullary parts of the floor, and are aberrant fibres from pontine nuclei destined for the cerebellum by the inferior peduncle.

The **pontine part** of the floor is characterized by an elongated elevation adjacent to the median sulcus, the *medial eminence* (of no importance, but not to be confused with the *median eminence* in the floor of the third ventricle, — p. 594). Its lower end is slightly more prominent and forms the *facial colliculus*, overlying the recurring fibres of the facial nerve and the underlying abducent nucleus. The floor at the lateral angle of the diamond is the *vestibular area*, overlying the vestibular nuclei. Between the facial colliculus and the vestibular area is a groove, the *superior fovea*, which leads up to the opening of the aqueduct. In the upper part of the fovea is a small area, the *locus caeruleus*, the bluish colour being caused by the underlying collection of pigmented cells which are noradrenergic with widespread connexions but uncertain function. They are part of the reticular formation.

The **medullary part** of the floor is smaller than the pontine part. Its lateral angle is occupied by the lower part of the vestibular area. From the inferior angle a groove (the *inferior fovea*) passes up to the medullary striae to meet the edge of the vestibular area. The groove divides the floor into two small triangular

regions. The medial one, with the apex down, is the *hypoglossal trigone*. Beneath it lies the twelfth nerve nucleus. The lateral triangle, apex upwards, lies between the hypoglossal and vestibular nuclei. It overlies the dorsal nucleus of the vagus and is the *vagal trigone*.

CEREBROSPINAL FLUID

Cerebrospinal fluid (CSF) is largely produced by the choroid plexuses of the third, lateral and fourth ventricles, but about 30% comes from other brain capillaries and seeps into the system by the extracellular fluid. The total volume of CSF is about 130 ml (at a pressure of approximately 130 mm of water), of which about 30 ml are within the ventricular system and 100 ml in the subarachnoid space (75 ml in the spinal part and 25 ml in the cranial part). The total production is over 500 ml per day, but there is constant circulation and resorption which takes place mainly through the arachnoid granulations (p. 559). There is also some drainage through the cribriform plate of the ethmoid bone in the anterior cranial fossa (p. 568) into the tissues of the nose and so into the cervical lymphatics. Changes in arterial pressure have little effect on CSF pressure, but increases in venous pressure, with the accompanying distension of veins and venous sinuses within the skull, are quickly reflected in CSF pressure. Lumbar puncture will of course reduce the pressure, and if the site of puncture continues to leak the pressure will remain low for some days.

The CSF provides a protective buffer for neural tissue and a waterbath in which the brain can float, thus effectively reducing the 1500 g weight of the brain to 50 g. It is also an important pathway for the removal of brain metabolites; there is no 'brain/CSF barrier', but the ependymal cells of the ventricles, which cover the choroid plexuses, have selective transport mechanisms and tight junctions between adjacent cells that provide a 'blood/CSF barrier' (similar to the blood/brain barrier — p. 600).

SUMMARY OF CRANIAL NERVE NUCLEI

The cranial nerve nuclei have been noted in the preceding account of the internal structure of the brainstem, but it may be helpful now to list them separately (Fig. 7.38). Summaries of the courses of the nerves themselves and of the effects of nerve lesions begin on page 629.

Those cranial nerves that have *motor nuclei* for supplying skeletal muscle (*somatic nuclei*, or *branchial* if derived from pharyngeal arches, p. 627) send their

fibres direct to the muscles concerned. Nuclei for cardiac and visceral muscle and for glands (*visceral nuclei*, p. 627) send their fibres for peripheral relay in autonomic ganglion cells.

The *sensory nuclei* of cranial nerves are in fact the cell bodies of the *second* sensory neurons; the cell bodies of the *first* neurons are outside the CNS, in the ganglia on the nerves themselves (corresponding to the posterior root ganglia of spinal nerves). The central processes of the cells in the nuclei go to the usual three sensory destinations: (1) to motor nuclei for reflex effects, (2) to the cerebellum and (3) to the opposite thalamus for relay to the sensory cortex. There is a solitary exception: the mesencephalic part of the trigeminal nucleus contains the cell bodies of the *first* neuron on the proprioceptive pathway from muscles of the orbit, face and (probably) tongue.

Oculomotor nerve nuclei

Two motor.

Motor: somatic, oculomotor nucleus near midline in floor of aqueduct of midbrain level with superior colliculi, for superior, medial and inferior rectus, inferior oblique and levator palpebrae superioris; *visceral*, Edinger-Westphal or accessory oculomotor nucleus, cranial to somatic part, to ciliary ganglion for sphincter pupillae and ciliary body.

Trochlear nerve nucleus

Motor, somatic, near midline of floor of aqueduct of midbrain level with inferior colliculi, for superior oblique.

Trigeminal nerve nuclei

One motor and three sensory.

Motor: branchial, motor nucleus of trigeminal, off centre in upper pons deep to floor of fourth ventricle, for mastication muscles, mylohyoid and tensor palati.

Sensory: somatic, in three parts continuous throughout the whole brainstem and extending into upper spinal cord. *Mesencephalic nucleus* in grey matter lateral to aqueduct of midbrain, for proprioception from muscles of mastication, face, tongue and orbit. *Main sensory nucleus* in lateral part of upper pons, lateral to motor nucleus, for touch from trigeminal area. *Spinal nucleus* in lower pons and throughout medulla, continuous below with gelatinous substance of spinal cord, for pain and temperature from trigeminal area. Afferent fibres from glossopharyngeal and vagus nerves may also reach these nuclei.

Abducent nucleus

Motor, somatic, near midline in pons deep to facial colliculus in floor of fourth ventricle, for lateral rectus.

Facial nerve nuclei

Two motor and two sensory.

Motor: branchial, facial nerve nucleus, off centre in pons, deep and lateral to facial colliculus; *visceral*, superior salivary nucleus adjacent to facial nucleus, secretomotor to pterygopalatine and submandibular ganglia, mainly for lacrimal and salivary secretion. *Sensory: branchial*, nucleus of tractus solitarius, lateral to dorsal nucleus of vagus in upper medulla, for taste fibres of chorda tympani from tongue and of greater petrosal nerve from taste buds of soft palate, *somatic*, sensory nuclei of trigeminal nerve for skin of external acoustic meatus and tympanic membrane.

Vestibulocochlear nerve nuclei

Six special sensory. *Cochlear nuclei*: two in medulla, buried ventrally and dorsally in inferior cerebellar peduncle, for hearing.

Vestibular nuclei: four in pons and medulla, under vestibular area in lateral angle of floor of fourth ventricle, for equilibrium.

Glossopharyngeal nerve nuclei

Two motor and two sensory.

Motor: branchial, nucleus ambiguus deep in upper medulla, for stylopharyngeus; *visceral*, secretomotor from inferior salivary nucleus adjacent to facial nucleus in lower pons, for otic ganglion and parotid secretion.

Sensory: visceral, nucleus of tractus solitarius, lateral to dorsal nucleus of vagus in upper medulla, for taste fibres from posterior third of tongue and for baroreceptors of carotid sinus (blood pressure) and chemoreceptors of carotid body (O_2 and CO_2 of blood); *somatic*, sensory nuclei of trigeminal nerve for ordinary sensation from mucous membrane of tongue, palate, pharynx and tonsil.

Vagus nerve nuclei

Two motor and two sensory.

Motor: branchial, nucleus ambiguus deep in upper medulla, for skeletal muscle of pharynx, upper oesophagus, palate and larynx, *visceral*, dorsal motor nucleus of vagus, below vagal trigone of upper medulla, for cardiac muscle and visceral muscle of thoracic and abdominal viscera.

Sensory: visceral, to nucleus of tractus solitarius, lateral to dorsal nucleus of vagus in upper medulla, for afferent fibres from heart, lungs and abdominal viscera, for baroreceptors of aortic arch (blood pressure) and chemoreceptors of aortic bodies (O_2 and CO_2 of blood), and for taste fibres from epiglottis; *somatic*, sensory nuclei of trigeminal nerve, for skin of external acoustic meatus and behind auricle, and perhaps for mucous membrane of pharynx and larynx (though these fibres may pass to nucleus of tractus solitarius).

Accessory nerve nuclei

Two motor.

Motor: branchial, for cranial part, nucleus ambiguus deep in upper medulla, fibres joining vagus for skeletal muscle of palate and pharynx; *somatic*, for spinal part, anterior horn cells of upper five or six cervical segments of spinal cord, for sternocleidomastoid and trapezius.

Hypoglossal nucleus

Motor, somatic, near midline below hypoglossal trigone of upper medulla, for muscles of tongue.

BRAIN – DEATH

The combined developments of ventilatory machines and transplantation surgery have underlined the need for defining the criteria for making a correct diagnosis of brain death—the irreversible cessation of brainstem function. In a comatose patient with irremediable *structural* brain damage due to a disorder that can lead to brain death (after excluding the effects of drugs, hypothermia and endocrine and metabolic disturbances, all of which may produce *functional* brain damage), brainstem reflexes must be shown to be absent in order to establish brain death. The following are the criteria normally adopted, with page references to their anatomical basis:

Fixed pupils, not reacting to light (p. 518), testing midbrain function.

No corneal reflexes (p. 517), testing pontine connexions between trigeminal and facial nerve nuclei.

No vestibulo-ocular reflexes (p. 515), testing connexions between vestibular nerve and eye-muscle nerves.

No gag reflex (p. 496) or response to bronchial stimulation by a catheter passed down the trachea (p. 286), testing vagal connexions in the medulla.

No motor responses in any cranial nerves on adequate nociceptive stimulation of any somatic area, e.g. testing for facial grimacing from pressure on the

supraorbital margins (connexions between trigeminal and facial nerve nuclei) or on the bases of fingernails (connexions between cervical spinal cord and facial nerve nuclei).

No respiratory movements when disconnected from the ventilator long enough to ensure that the arterial CO_2 rises above the threshold for respiratory stimulation ($P_{CO_2} > 50$ mm Hg, 6.7 kPa).

PART 3 CEREBELLUM

The **cerebellum** can be considered as a brainstem nucleus which, in the course of vertebrate evolution has become so big that it has grown increasingly far back on to the dorsal surface of the brainstem (Fig. 7.32). It occupies the posterior cranial fossa, and consists of two *hemispheres* united in the midline by the *vermis*. Three *peduncles* connect each hemisphere to the three parts of the brainstem. The superior peduncle enters the midbrain, the middle peduncle consists of the transverse fibres of the pons and the inferior peduncle connects it to the medulla. The ventral surface of the vermis lies upon the superior medullary velum above and the roof of the medullary part of the fourth ventricle below.

The ancients gave many fanciful names to different parts of the cerebellar surface. The parts of the vermis so named chance to have functional and morphological significance, but the named parts of the hemispheres are functionally meaningless and can be ignored. But it is helpful to correlate certain parts of the cerebellum with their evolutionary history. Reference will be made below to the *archaeocerebellum*, the oldest part and concerned with balance (vestibular mechanisms); the *palaeocerebellum*, which developed later to assist in the control of limb movements (spinal mechanisms); and the *neocerebellum*, the most recently developed part which evolved in association with the increasing complexity of the cerebral hemispheres (cerebral mechanisms).

The *superior surface* of the cerebellum is bounded posteriorly by a convex border that lies below the attached margin of the tentorium cerebelli. From this border the superior surface slopes concavely upwards, in conformity with the shape of the tentorium, to the highest part of the cerebellum, which lies at the tentorial notch. The *posteroinferior surfaces* are boldly convex below the posterior border. Known to the ancients by the appropriate name of 'nates' (buttocks), they occupy the concavities in the occipital bone. Between them lies

a deep groove, the *vallecula*, which lodges the three parts of the inferior vermis.

The surface of the cerebellum is indented by fine slit-like *sulci*, between which lie more or less parallel cerebellar *folia*. In the main the *folia* and *sulci* lie transversely from side to side across the whole extent of the cerebellum. Several transverse fissures pass deeply into the substance; the *folia* extend into their depths.

A well-marked groove, the *horizontal fissure* (of no functional significance), indents the convex posterior border. This is the deepest sulcus of all; it extends from side to side and around towards the front, where its margins embrace the middle peduncle. Anterior to it, on the superior surface, is a much shallower groove, the **primary fissure**; this is significant, for it separates palaeocerebellum and neocerebellum.

The **hemispheres** consist, then, of a small *anterior lobe* on the superior surface in front of the primary fissure and a large *posterior lobe* comprising the rest of the hemisphere behind the primary fissure (Fig. 7.32). This division possesses not only the advantage of simplicity, but is of morphological and functional significance: the anterior lobe is part of the palaeocerebellum, the posterior lobe forms the neocerebellum.

The **vermis** consists of superior and inferior parts, separated from each other by the neocerebellar posterior lobes, which meet in the midline behind the primary fissure.

The *lingula* is that part of the superior vermis which lies in contact with the superior medullary velum. On the superior surface of the anterior lobe there is no

line of demarcation between vermis and cerebellar hemispheres.

In the *vallecula* the inferior vermis consists of three small lobules which retain their ancient names of pyramid, uvula and nodule. The *nodule* lies highest, on the roof of the fourth ventricle. Projecting laterally from each side of the nodule is a slender band of white matter whose bulbous extremity, capped with grey matter, can be seen from in front, lying in the angle between cerebellum and pons. This is the *flocculus*; the choroid plexus of the fourth ventricle projects just below it (Fig. 7.1). The two flocculi and the nodule form the *flocculonodular lobe*; this and the *lingula* represent the archaeocerebellum.

The *uvula* and *pyramid*, larger than the nodule, occupy the remainder of the *vallecula*. With the anterior lobe, they form the palaeocerebellum. Projecting laterally is a slender lobule, the *paraflocculus*, attached mainly to the pyramid. It lies beneath the flocculus. Slender in man, it is relatively enormous in the marine mammals (it may be concerned with preserving rotary stability about the long axis of the body).

Morphology

The cerebellum is imagined to have three distinct morphological parts, evolved sequentially, and *possessing different functions*.

The *archaeocerebellum* has vestibular connexions only. It is represented in mammals by the *lingula*, the *uvula* and the *flocculonodular lobe*. Lesions of this part

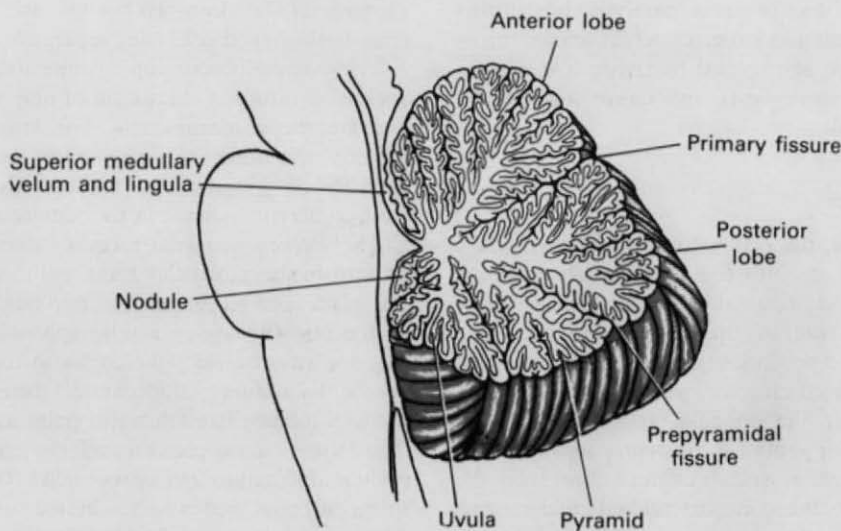


Fig. 7.32 Sagittal section of the cerebellum.

produce vestibular symptoms: disturbances of equilibrium with no alteration to spinal reflexes. Fine movements are well performed, there is no nystagmus, no tremor and no alteration of muscle reflexes. The condition is known as trunk ataxia — the victim walks as if drunk.

The *palaeocerebellum*, which evolved between the lingula at the front and flocculonodular lobe at the back, so splitting the archaocerebellum, has spinal connexions (spinocerebellar tracts), and is concerned with postural and righting reflexes. It is represented in mammals by the anterior lobe, the pyramid and paraflocculus and the uvula. Lesions of this part cause great disturbance of postural mechanisms with increased muscle reflexes.

The *neocerebellum*, superimposed dorsally upon the palaeocerebellum, evolved between the anterior lobe and the pyramid, so splitting the palaeocerebellum. It comprises the whole of the cerebellar hemispheres behind the primary fissure (i.e. it is synonymous with the posterior lobe, as distinct from the inferior vermis). It is best developed in man and has cerebropontine connexions from the pontine nuclei via the middle peduncle. It is concerned in feedback circuits with the basal nuclei and the cerebral cortex. It functions in the control of the synergic background of muscle tone in the performance of accurate voluntary movements (p. 8). Lesions of the neocerebellum lead to such clinical features as hypotonia, diminished or pendulum muscle jerks, intention tremor, dysdiadochokinesia and nystagmus.

The essential function of the cerebellum can thus be briefly summarized as the co-ordination movement. Cerebellar lesions do not cause paralysis, but disturbances of movement and balance such as ataxia, intention tremor (absent at rest and best seen towards the end of the finger-nose test), nystagmus and speech defects (dysarthria).

Internal structure

Like the cerebrum, the cerebellum is surfaced with a *cortex* of grey matter, with the white matter internal. Each hemisphere contains subcortical nuclei of grey matter near the roof of the fourth ventricle. The **dentate nucleus** is the largest and most important. It forms a large crenated crescent, resembling the inferior olivary nucleus in the medulla (Fig. 7.33), open towards the superior peduncle. Its main connexions are from the neocerebellum, and its efferent fibres leave the hilum and pass to the contralateral red nucleus and thalamus. Three small masses lie medial to the hilum of the dentate nucleus, the *emboliform*, *globose* and *fastigial*

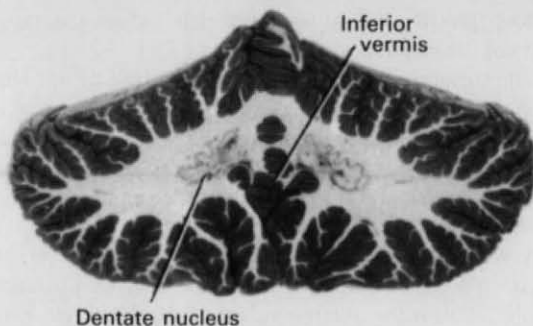


Fig. 7.33 Coronal section of the cerebellum, from the front, through the dentate nucleus.

nuclei (in that order, EGF from lateral to medial). From their proximity to the fourth ventricle these nuclei are known collectively as the **roof nuclei** of the cerebellum. The fastigial nucleus belongs to the archaocerebellum, the other two to the palaeocerebellum.

The cerebellar cortex is very characteristic and is of *identical appearance in all areas*. Two equally thick cortical layers sandwich a single layer of Purkinje cells between them. The *molecular layer* of the cortex lies on the surface; it consists almost entirely of fibres, with a few cells scattered among them. These are called *basket cells* because their axons arborize in basket shape around the Purkinje cell bodies. The *granular layer* lies deep to the molecular layer and consists overwhelmingly of small round granular cells tightly packed together (in low power appearance somewhat resembling the lymphocytes in lymphoid tissue). The layer of *Purkinje cells* lies between the two and consists of very large flask-shaped cells lying separately at intervals.

The essential microscopic connexions are as follows. Incoming (afferent) fibres are of only two kinds. Both activate the Purkinje cells, one (the *climbing fibre*) directly, the other (the *mossy fibre*) through the intermediary of granular and basket cells. The Purkinje axons (efferent) synapse in the dentate and other nuclei.

The *Purkinje dendrites* form an elaborate branching pattern in the molecular layer. All the branches lie in one plane, like an ornamental tree spread out on a wall or the cross-beams on a telegraph pole. The plane of the dendrites lies at right angles to the long axis of a cerebellar folium. Adjacent dendrites lie crosswise along a folium, like telegraph poles along a roadside. The *Purkinje axons* pass through the granular layer, and relay in the dentate and other nuclei. Thence fibres run in the superior peduncle to the red nucleus, thalamus and cerebral cortex of the opposite side.

The *climbing fibres* (the terminals of pontine and

vestibular fibres) pass from the white matter through the granular layer and weave around the Purkinje dendrites in the molecular layer.

The *mossy fibres* (terminals of spino- and olivocerebellar fibres) arborize as a tuft around a granular cell. The axon of the granular cell passes out into the molecular layer and bifurcates in T-shaped manner. Some of these fibres arborize around the few basket cells, the majority arborize directly with the Purkinje dendrites. The axon of the basket cell divides and arborizes around the cell bodies of some 500 Purkinje cells.

Note that a climbing fibre directly activates one Purkinje cell, while a mossy fibre indirectly activates many hundred Purkinje cells. Note also the general rule that incoming fibres pass directly to the cortex, not to subcortical nuclei, and that efferent fibres arise from subcortical nuclei, not from the cortex. To these statements there are some (clinically unimportant) exceptions: a few cerebellovestibular fibres run straight from the cortex back to vestibular nuclei, and some vestibulocerebellar fibres enter the fastigial nucleus without proceeding to the cortex. A few olivo- and reticulocerebellar fibres may also pass to subcortical nuclei.

Cerebellar peduncles and connexions

The superior and middle peduncles are simple; the inferior peduncle contains a great mixture of fibres.

The **superior peduncle** contains a preponderance of *efferent* fibres, passing from the dentate nucleus to the red nucleus, thalamus and cortex of the opposite side. It also contains the anterior spinocerebellar tract, passing to the anterior lobe (palaeocerebellum) and tectocerebellar fibres from the midbrain.

The **middle peduncle** contains fibres from the pontine nuclei of the opposite side; they are *afferent* to the neocerebellum.

The **inferior peduncle** is predominantly *afferent*. The only *efferent* tract of note is the *cerebellovestibular tract*, from the roof nuclei to the vestibular nucleus of the same side but there are also some cerebello-olivary and cerebelloreticular fibres. The afferent fibres to the vermis (archaeocerebellum) form the *vestibulocerebellar tract*, from the vestibular nucleus of the same side. Those to the anterior lobe (palaeocerebellum) comprise the *posterior spinocerebellar* and *cuneocerebellar tracts*, the latter consisting of posterior external arcuate fibres from the accessory cuneate nucleus (for proprioception from the upper limb). Those to the posterior lobe (neocerebellum) form the *olivocerebellar tract* (from the olivary nuclei of the opposite side), and there are also fibres from pontine nuclei and the reticular formation.

Blood supply

Two arteries supply the large convex under surface and one artery supplies the small upper surface of each cerebellar hemisphere. They anastomose with each other on the cerebellar surface, but their perforating branches into the cerebellum are, as elsewhere in the nervous system, end arteries.

The **posterior inferior cerebellar artery** is one of the most tortuous arteries in the body, and is the largest branch of the vertebral artery. It arises ventrally from the vertebral artery, near the lower end of the olive, and spirals back around the medulla below the hypoglossal rootlets and then between the rootlets of the glossopharyngeal and vagus nerves. It supplies the choroid plexus of the fourth ventricle and is distributed to the vallicula and the back of the cerebellar hemispheres. It supplies, in passing, the adjacent part of the medulla as described on page 611.

The **anterior inferior cerebellar artery** arises from the basilar artery at the lower part of the pons and passes back on the inferior surface of the cerebellar hemisphere, supplying this surface and the adjacent flocculus. It may give rise to the labyrinthine artery if it has not arisen from the basilar.

The **superior cerebellar artery** arises near the termination of the basilar and passes laterally to wind around the cerebral peduncle below the fourth nerve. It is distributed over the superior surface of the cerebellum.

Venous drainage is from the surface of the cerebellum into the nearest available venous sinus of the dura mater. Thus the superior and posterior surfaces drain into the straight and transverse sinuses, inferior surfaces into the inferior petrosal, sigmoid and occipital sinuses. The superior vermis drains anteriorly into the great cerebral vein at its entrance into the straight sinus.

PART 4 SPINAL CORD

The **spinal cord**, properly but not often called the spinal medulla, is a cylinder, somewhat flattened from front to back, whose lower end tapers into a cone. Ventrally it possesses a deep midline groove, the *anterior median fissure*, and dorsally it shows a shallow *posterior median sulcus*, from which a *posterior median septum* of neuroglia extends into its substance. The posterior median septum within the spinal cord is attached to the incomplete posterior median septum of arachnoid in the subarachnoid space.

In the fetus the spinal cord extends to the lower limit of the spinal dura mater at the level of S2 vertebra. The spinal dura remains attached at this level throughout life, but the spinal cord becomes relatively shorter, which is to say that the bony spinal column and the dura mater grow more rapidly than the spinal cord. Thus at birth the conus medullaris lies opposite L3 vertebra and does not reach its permanent level opposite L1 or L2 until about the age of 20 years. The spinal nerve roots, especially those of the lumbar and sacral segments, thus come to slope more and more steeply downwards (see below).

The spinal cord possesses two symmetrical enlargements which occupy the segments of the limb plexuses: as the **cervical enlargement** for the brachial plexus and the **lumbosacral enlargement** for the lumbar and sacral plexuses. They occupy, *in the cord*, the segmental levels of the plexuses concerned (C5 to T1 for the cervical enlargement and L2 to S3 for the lumbosacral enlargement), but their levels measured by vertebrae are, of course, quite different. Thus the cervical enlargement lies roughly corresponding to the vertebrae C3 to T1, but the lumbosacral extends only from T9 to L1. Both enlargements are due to the greatly increased mass of motor cells in the anterior horns of grey matter in these situations.

The spinal meninges have been described on page 574.

Spinal nerve roots

No spinal nerves lie inside the spinal theca; indeed, no nerve lies, strictly speaking, within the vertebral canal. The **anterior** and **posterior roots** of the spinal nerves unite *within the intervertebral foramina*. Within the subarachnoid space the nerve roots are attached to the spinal cord each by a series of *rootlets*. Each *anterior root* is formed by three or four rootlets which emerge irregularly along the anterolateral surface of the spinal cord. Each *posterior root* is formed by several rootlets, attached vertically to the posterolateral surface of the cord. A short distance from the cord the rootlets are combined into a single root (Fig. 6.98, p. 575). The anterior and posterior roots pass from the cord to their appropriate intervertebral foramina, where each evaginates the dura mater separately before uniting to form the mixed spinal nerve. The **ganglion** on the posterior nerve root lies in the intervertebral foramen, within the tubular evagination of dura and arachnoid immediately proximal to the point of union of anterior and posterior nerve roots. However, the posterior root ganglia of *cervical* nerves lie just *lateral* to the intervertebral foramina, in contact with the vertebral artery (Fig. 6.96, p. 573). For

all levels from C1 to L1 vertebrae the anterior and posterior nerve roots pass in front of and behind the denticulate ligament respectively, and evaginate the dura mater between the denticulations (Fig. 6.98, p. 575). In conformity with the shortness of the spinal cord, the lower a nerve root the more steeply it slopes down to the intervertebral foramen. The upper cervical roots are horizontal, the upper thoracic roots first slope down to their point of evagination of the meninges only to become kinked upwards at an angle to reach their foramen (Fig. 7.34). Below L1 vertebra the roots pass almost vertically downwards through the subarachnoid space, forming the **cauda equina**; note that this consists *not* of spinal *nerves* but of *nerve roots*. The *filum terminale* (pia mater, p. 575) extends down from the tip of the conus medullaris among the nerve roots of the cauda (but is not classified as part of the cauda).

The roots of the **spinal part of the accessory nerve** emerge from the lateral surface of the upper five or six segments of the cord, *behind the denticulate ligament*. They unite into a single trunk which passes upwards through the foramen magnum into the cranium to join the cranial root (Fig. 6.96, p. 573).

INTERNAL STRUCTURE

The spinal cord consists of a central mass of **grey matter** (cell bodies), in the form of a fluted column surrounding the central canal, enclosed in a cylindrical mass of **white matter** (fibres) (Fig. 7.35). It is almost divided into two halves by the anterior median fissure and the posterior median septum. The septum extends

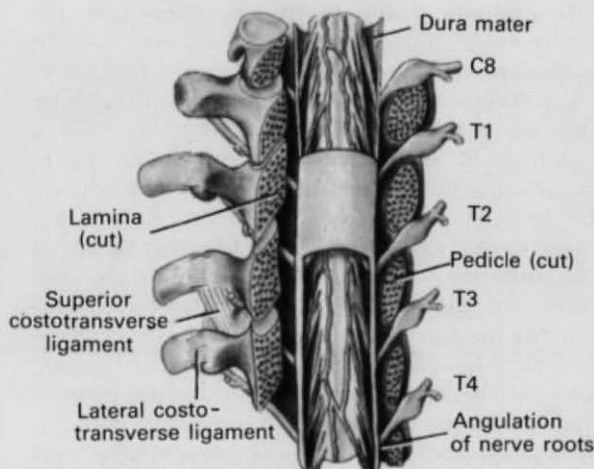


Fig. 7.34 Upper thoracic spinal nerve roots, from behind, showing the upward angulation of the roots as they emerge from the spinal theca.

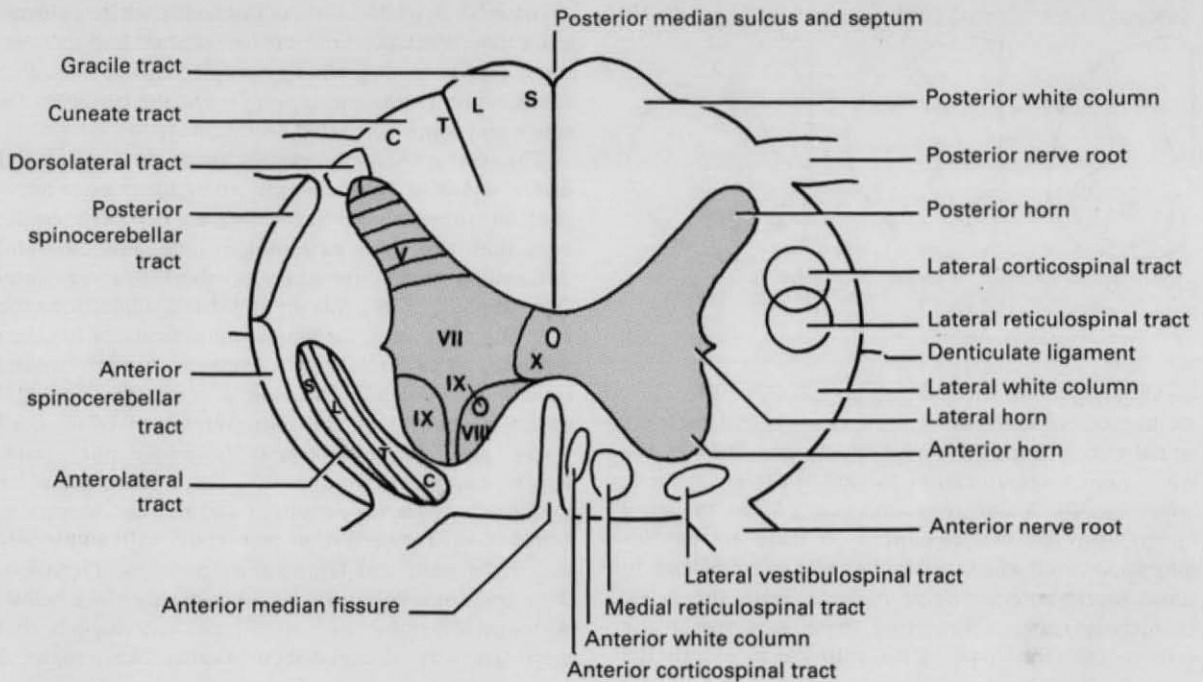


Fig 7.35 Cross-section of the spinal cord showing the main tracts and laminae of grey matter.

forwards as far as the *grey commissure* (the central limb of the H in cross-section); it connects the grey matter of the right and left halves of the cord. Centrally it contains the *central canal*, the tiny downward continuation of the cavity of the fourth ventricle and like it lined by ependyma. It extends into the upper few millimeters of the filum terminale. The anterior fissure does not completely separate the white matter — a narrow *white commissure* lies anterior to the grey. Both the grey and white matter of the right and left halves are divided into *anterior, lateral and posterior columns* of cells or fibres. From the cross-sectional appearance the grey columns are usually referred to as **anterior, lateral and posterior horns**, and it is convenient to use this term for the *grey matter* (containing nerve cell bodies), leaving *column* to indicate *white matter* (containing nerve fibres, i.e. tracts). Although transverse sections of the cord (like those of the brainstem) have to be studied in order to define the positions of tracts and cell groups, from the functional point of view it is necessary to 'think vertically' as well; although the component parts of reflex arcs, for example, may lie within a segment as seen transversely, most activity within the cord is in an up or down direction, and this is what must be appreciated.

The shapes of the white columns and grey horns in sections enables the three regions to be distinguished

(Fig. 7.36). The posterior white columns are largest in the cervical region, and the anterior grey horns largest in the cervical and lumbar regions.

The following account of selected cell groups and tracts is deliberately synoptic and simplified in order to emphasize the most important features as far as general anatomy and clinical relevance are concerned: those who need further information will consult specialist texts.

Grey matter

The central grey matter appears in sections like an H-girder (Fig. 7.36), especially in the thoracic region. The **posterior horn** stretches to the surface of the cord, but the **anterior horn** falls short of it. The cervical and lumbosacral enlargements are due to a great increase in the number of anterior horn cells, to provide fibres for the great nerve plexuses. The more *medial* anterior horn cells are concerned with the innervation of *trunk* musculature, with those more *laterally* placed supplying the *limbs*. Furthermore, the more *ventral* cells of the lateral group supply *proximal* limb muscles, and those more *dorsally* placed innervate the more *distal* limb muscles.

Between the limb enlargements, from segments T1 to L2, there is a small **lateral horn**, containing pregan-

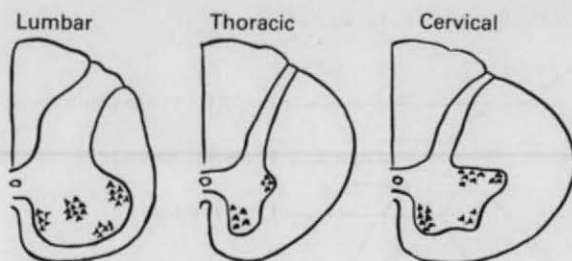


Fig. 7.36 Cross-section of the spinal cord in the lumbar, thoracic and cervical regions.

glionic *sympathetic* cell bodies (Fig. 1.20C, p. 29). Their axons pass out in the anterior nerve roots and enter the spinal nerves from T1 to L2 which they leave in the white rami communicantes passing to the sympathetic trunk (p. 30). A similar group of cells forms the small lateral horn in *sacral segments 2–4*; these are preganglionic *parasympathetic* cell bodies whose axons leave in those sacral anterior nerve roots to form the pelvic splanchnic nerves. Note that these parasympathetic cells in the sacral part of the cord are in exactly the same position in the cord as the sympathetic cells at higher levels.

The cells of the grey matter in each half of the cord lie in specific functional groups or laminae, designated by the Roman numerals I to X (Fig. 7.35). (The original research by Rexed defining these areas was carried out on the cat, but has been confirmed for primates and is believed to apply to the human cord also). Among the more important cell groups in the various laminae are those of lamina II which constitute the gelatinous substance; the cells of laminae III to VI form the nucleus proprius among which the cells of lamina V are a main source of anterolateral tract (spinothalamic and spinoreticular) fibres; lamina VII contains in its medial part the thoracic nucleus and laterally the thoracolumbar (sympathetic) and sacral (parasympathetic) lateral horn cells; other cells of lamina VII, together with those of lamina VIII, are interneurons involved in co-ordinating motor activity and projecting to lamina IX; lamina IX contains the α and γ motor neurons which innervate skeletal muscle, arranged in medial and lateral groups for axial and limb musculature as mentioned above.

White matter

The white matter of the spinal cord contains three kinds of fibres—ascending, descending and intersegmental—and is divided into the three columns by the fluted grey matter and the attached nerve roots.

In each half of the cord the **posterior white column** lies between the posterior median septum and the posterior grey horn. It is wholly occupied by the ascending fibres of the *gracile* and *cuneate tracts*, the pathways for touch and some associated sensations (p. 623).

The rest of the white matter forms the **lateral and anterior white columns**, the emerging anterior nerve roots providing a convenient dividing line between the two. Both these columns contain long ascending and descending tracts. In addition, short intersegmental (*proprio-spinal*) fibres run up and down adjacent to the central grey matter, forming communications between segments. The lateral white column contains (among others) the lateral corticospinal tract, the principal motor pathway and the most important of all cord tracts, and the anterolateral (spinothalamic) tract, which extends into the anterior white column and is the pathway for pain (nociception) and thermal sensations (differences between hot and cold), all commonly called the pain and temperature pathway. Details of these and some other significant tracts are given below. Although diagrams such as Figure 7.35 suggest that tracts are very circumscribed bundles like peripheral nerves, there is much intermingling of fibres and (except in the posterior columns) there are no sharp boundaries to tracts.

Afferent pathways

There are three possible destinations for all incoming fibres: the cortex of the opposite cerebral hemisphere, via thalamic relay, for conscious sensation; the cerebellum, for muscular co-ordination; and the brainstem or spinal cord, for reflex actions.

As a guiding principle it is usually stated that *afferent* impulses are conveyed to the cerebral cortex by *three groups of neurons*. While this is a convenient concept and accurate enough for understanding the main long-fibre components of neuronal pathways, it takes no account of the vast numbers of interneurons in the central nervous system whose activities may be highly important in modifying impulse conduction though difficult to investigate. The cell bodies of the first group of neurons (*first neurons* or *first order neurons*) always lie *outside the central nervous system*: in the posterior root ganglia of spinal nerves or the equivalent ganglia of cranial nerves. (There is one odd exception: the cell bodies of the proprioceptive neurons of the trigeminal nerve are not in the trigeminal ganglion but are within the central nervous system, in the mesencephalic nucleus—p. 607.) The cell bodies of the *second neurons* are in the spinal cord or brainstem, and those of the *third group* are in the thalamus.

Efferent pathways

For the control of the skeletal muscles supplied by spinal nerves, two main systems of neurons are involved. One can be called the **direct corticospinal pathway**, consisting essentially of *two groups of neurons*. The cell bodies of the first are in the cerebral cortex, and their fibres extend through the internal capsule and brainstem to the anterior horn cells of the cord; these are the corticospinal fibres whose course through the cerebral hemisphere and brainstem has already been considered (p. 612), together with the corresponding corticonuclear fibres going to the motor nuclei of cranial nerves). These fibres, often called **pyramidal** (p. 612), with their cortical cell bodies can also be known as the **upper motor neurons**. The second neurons of this direct motor pathway are the anterior horn cells and their axons which end as the motor endplates on skeletal muscle fibres. These neurons (and those of the motor nuclei of cranial nerves) are often called the **lower motor neurons**.

The other system involves a whole *series of neurons* on the way to anterior horn cells (in contrast to the single pyramidal group). For example, cortical cells may send their axons to pontine nuclei, from which fibres run to the cerebellum (corticopontocerebellar pathway) which in turn may project to the red, reticular, vestibular and olivary nuclei, all of which can communicate with the same anterior horn cells as pyramidal fibres. Other cortical fibres run to the basal nuclei (corpus striatum, p. 581) and thalamus, with projections from them to the red, reticular and subthalamic nuclei and the substantia nigra. These brainstem nuclei can also be activated by reflex sensory pathways (e.g. light and sound). From some of these brainstem groups fibres descend to synapse with the same anterior horn cells that have received corticospinal fibres. None of these fibres has passed through the pyramid of the medulla, hence the name **extrapyramidal**, and because none has passed *uninterruptedly* from the cortex to anterior horn cells they can also be called **indirect corticospinal pathways**. Thus there are many possible combinations of routes from cortex to cord, and ample opportunity for influencing the responses of anterior horn cells. Since anterior horn cells (and the equivalent motor nuclei of the brainstem) are at the 'receiving end' of both direct and indirect corticospinal pathways, they and their axons (the lower motor neurons) are often called the 'final common path'.

Although the purists may argue about the precise definitions of the terms pyramidal, extrapyramidal and upper motor neuron, they remain widely used.

Ascending tracts

The most important ascending tracts fall into two groups. Those in the **posterior white columns** are concerned with light (discriminative) touch and some other sensations that use the same tracts: vibration sense, proprioception (muscle-joint or kinaesthetic sense, the conscious appreciation of body position and movement), and the sense of fullness of the bladder and rectum. Those in the **lateral and anterior white columns** are concerned with pain (nociception) and temperature sensations, crude touch, and the sensations of itch, tickle and sexual orgasms. Here also are tracts to the cerebellum, for muscular co-ordination.

The posterior white column is wholly occupied by ascending fibres of the **gracile and cuneate tracts**. Their cell bodies lie in the posterior root ganglia of spinal nerves, and the fibres (large myelinated) enter the cord from the medial side of the posterior nerve roots. Some branches from the incoming posterior root fibres are short and take part in segmental reflex arcs, but it is the long ascending fibres that form the tracts. The fibres from the lowest parts of the body (segmentally speaking) lie nearest the midline, and incoming fibres are added progressively laterally, i.e. the column is *laminated*. In this way fibres from the perineum, lower limb and lower trunk form the gracile tract, and those from the upper trunk and upper limb form the more lateral cuneate tract. The two tracts end in the lower part of the medulla by synapsing with the cells of the gracile and cuneate nuclei respectively. The axons from these (second order) nuclei immediately decussate to form the **medial lemniscus** which runs through the brainstem to the thalamus (p. 613). After relay there, the axons of the third group of neurons pass via the internal capsule to area SmI of the cerebral cortex.

Tests for the types of sensation transmitted by the posterior columns include those for light touch, such as gentle stroking of the skin with the fingers or cotton wool. Position sense (often called postural sense) is tested by the examiner passively moving finger or great toe joints with the patient's eyes closed, to see whether the direction of movement can be appreciated. If upper limb position sense is disturbed the patient cannot hold the outstretched limb and fingers steady with the eyes closed, nor perform the finger-nose test accurately. Similarly, lower limb position sense is tested by standing upright with the feet together and then closing the eyes. Without the visual sense to relate to the environment, there will be loss of balance with the eyes shut (Romberg's sign), if there is loss of this posterior column sense. For the same reason there will be difficulty with walking in the dark, or keeping the

balance when washing the face with the eyes shut. These are examples of sensory ataxia. (With labyrinthine lesions or cerebellar ataxia there is little difference whether the eyes are open or shut.) Vibration sense, which is also conducted by the posterior columns, is tested by applying a vibrating tuning fork (128 Hz, middle C) to a bony prominence such as the lateral malleolus.

The two-point discrimination test is important because it not only involves the peripheral and central pathways, but the cerebral cortex as well. Two points 3 mm apart are normally distinguishable on the finger pads. Stereognostic sense (ability to appreciate the size and shape of objects in the hand) also requires the intact cortex.

The main ascending tract of the lateral and anterior white columns is now known as the **anterolateral tract**, the pathway for pain and temperature and crude touch. It has for long been divided into the lateral and anterior spinothalamic tracts, but it appears more accurate to consider it as one. It is a large bundle lying in front of the lateral corticospinal tract (and therefore in front of the level of attachment of the denticulate ligament) and extending into the anterior white column (and therefore penetrated by the efferent axons of anterior horn cells).

The pain fibres in peripheral nerves are of two kinds: small C fibres, unmyelinated and slow-conducting, for the dull, aching type of pain ('slow pain'), and A δ fibres, thinly myelinated and fast-conducting for the sharp, pricking type of pain ('fast pain') and also for temperature conduction. On entering the cord from the posterior nerve roots (from cell bodies in the posterior root ganglia), the fibres form the **dorsolateral tract** (of Lissauer). This is a composite name for these incoming fibres, which run up or down at the tip of the posterior horn for one or two segments before synapsing with cells of the **gelatinous substance** (mainly lamina II) which themselves may provide short intersegmental axons that enter this tract.

Through various interneurons in the region of the tip of the posterior horn, the impulses are passed on to the second order neurons whose fibres form the **anterolateral tract**. The tract originates mainly from cell bodies in laminae I and V, and the fibres cross to the opposite side of the cord in front of the central canal. Although in the lowest part of the cord the fibres from any one segment cross transversely, the crossing takes place more and more *obliquely* at higher levels so that in the cervical region the decussation may require the height of four or five segments before it is completed. The tract is *laminated*, with fibres subserving impulses from the sacral segments lying most laterally, while those from cervical segments are the most deeply placed (Fig. 7.35). The fibres for crude touch occupy the more

medial part of the tract (the old *anterior spinothalamic part*), and have crossed less obliquely than the pain and temperature fibres.

Only about 10% of anterolateral tract fibres pass *directly* to the thalamus, via the spinal lemniscus of the brainstem (p. 613). The other 90% of fibres synapse with cells of the brainstem reticular formation, where there may be multiple connexions before the onward transmission of impulses to the thalamus; this is the *spinoreticulothalamic pathway*. Third order neurons then pass from the thalamus to the sensory cortex. Note that, strictly speaking, these pain and temperature pathways form an exception to the three-neuron rule; in the gelatinous substance and other parts of the posterior horn there are various interneuronal connexions, and there are undefined numbers of synapses in the reticular formation. Nevertheless there are only three groups of neurons with *long* fibres, so the general concept of a three-neuron pathway is still useful.

The extent to which the anterolateral tract cells are stimulated to pass on impulses from spinal cord to brain is subject to control and modification by both spinal and supraspinal influences. For example, large myelinated (Ia) fibres from mechanoreceptors, apart from passing up in the posterior white columns, give branches that synapse with anterolateral tract cells, and their effect is to inhibit transmission from the tract cells ('closing the gate' to nociceptive impulses); hence the effectiveness of rubbing an injured part to reduce the pain. Other inhibitory influences come from supraspinal levels via the reticular formation, so that cerebral and limbic activities such as memory, past experience and emotion can depress or even completely suppress pain — as happens in battle casualties who may feel no pain at the time of severe injury. The investigation of pain transmission and perception has been given great impetus by the discovery that certain areas of the nervous system (e.g. the thalamus, limbic system and gelatinous substance) produce their own morphine-like substances (endogenous opioid peptides), such as endorphins and enkephalins, which can inhibit pain by binding to receptors on parts of the pain pathway. Some of these substances may act as modulators of the transmission of pain impulses or may themselves be transmitters. They do not pass the blood/brain barrier (p. 600) and so cannot be given intravenously.

The common tests for pain sensation are by pinprick for superficial pain (spinothalamic) and by pinching or squeezing a fold of skin, muscle or tendon, such as the Achilles tendon, for deep pain (spinoreticulothalamic). Temperature sense can be estimated by touching the skin with a cold metal object and a test-tube of warm water.

In the operation of *anterolateral cordotomy* for the relief of persistent pain, the lateral part of the anterolateral tract is severed to block upward transmission through the tract. The knife is inserted *in front of* the line of attachment of the denticulate ligament, so avoiding damage to the corticospinal tract which lies behind this. Because of the obliquity of the crossing of fibres, the cut must be made several segments above the desired level of analgesia. Although cordotomy should theoretically result in permanent pain relief, it rarely lasts for more than a few months (2 years at the most) — an example of the plasticity of the nervous system and the way new pathways can develop.

The **anterior** and **posterior spinocerebellar tracts** convey unconscious proprioceptive information from cord to cerebellum, as their names imply. Some fibres from posterior root ganglion cells enter the cord through the posterior roots and synapse with the cells of the *thoracic nucleus* (Clarke's column) in lamina VII at the base of the posterior horn in all the thoracic and first two lumbar segments of the cord. The axons of these cells move to the lateral edge of their *own side* of the cord as the *posterior spinocerebellar tract*, which runs up into the medulla to reach the cerebellum by the *inferior peduncle* (p. 619). Other incoming fibres synapse with other posterior horn cells, mainly of lamina VII, in lumbar and sacral segments; these give rise to fibres which mostly cross to the opposite side to form the *anterior spinocerebellar tract*, at the margin of the cord behind the anterior nerve roots. It takes an unexpectedly long route to the cerebellum, running through the brainstem to the midbrain and doubling back into the *superior cerebellar peduncle* (p. 619). From cervical nerves, impulses destined for the cerebellum do not travel by these spinocerebellar tracts (since the thoracic nucleus does not extend above T1 level); they reach the *accessory cuneate nucleus* by the cuneate tract, and thence by the cuneocerebellar tract enter the inferior peduncle (p. 619).

A number of ill-defined groups of ascending fibres such as spinoreticular, spino-olivary, spinotectal, spinovestibular and spinospinal provide further connexions between the cord and brainstem and between different parts of the cord for reflex activities.

Descending tracts

The **lateral corticospinal tract**, the most important of all tracts, is formed from the motor decussation in the lower medulla, and the cortical origin of the fibres has already been described (p. 612). The tract lies in the lateral white column at a level behind the attachment of the denticulate ligament. The 'arm' fibres cross at a

slightly higher level than the 'leg' fibres. The tract gets smaller as it passes down the cord since fibres are leaving it at all levels to reach the anterior horn. Almost all (98%) of the fibres end by synapsing with interneurons (laminae VII and VIII) which in turn project to the α and γ motor neurons of lamina IX of the anterior horn. (The 2% of fibres that synapse directly with motor neurons are those originating from the giant Betz cells.) About 55% of corticospinal fibres end on cervical and first thoracic anterior horn cells, i.e. more than half of the corticospinal fibres are concerned with the motor supply of the upper limb, leaving 20% for trunk supply and 25% for the lower limb. Because of the medullary decussation, the cerebral cortex of one side controls the muscles of the contralateral side.

The relatively unimportant uncrossed fibres in the medulla continue as the **anterior corticospinal tract**, adjacent to the anterior median fissure, but it goes no lower than the upper thoracic part of the cord. The fibres eventually cross to the opposite anterior horn.

The most important *extrapyramidal tracts* are the reticulospinal and the vestibulospinal tracts. The **lateral reticulospinal tract** arises from the medullary part of the reticular formation and the fibres run down in the lateral white column, *largely intermingled with corticospinal fibres*. Its influence on anterior horn cells is facilitatory. The **medial reticulospinal tract** comes from cells in the pontine reticular formation and descends in the anterior white column, to have an inhibitory action on motor neurons. The **lateral vestibulospinal tract** arises from the lateral vestibular nucleus of the medulla and runs down the cord approximately through the anterior nerve root region. The reticulo- and vestibulospinal fibres synapse with cells in laminae VII and VIII, in turn projecting to the lamina IX motor neurons. The vestibulospinal tract primarily affects trunk and limb girdle musculature, and is of great importance for posture and balance.

The **descending sympathetic tract**, whose fibres were seen in the brainstem in the region of the spinal lemniscus, provides a link between the hypothalamus and the thoracolumbar lateral horn cells (lamina VII). In the cord the fibres have recently been shown to lie where they might be expected, adjacent to the lateral horn. Presumably similar fibres run to the parasympathetic cells of the sacral lateral horn.

Clinically it is important to distinguish between upper and lower motor neuron lesions. The *lower motor neuron lesion* produces a *flaccid paralysis* of muscles with decreased or absent reflexes. *Spastic paralysis* with increased reflexes, clonus and an extensor plantar response (p. 28) is regarded as evidence of an *upper motor neuron lesion*. However, it should be noted that a

pure pyramidal lesion (rare, but possible from a lesion confined to the pyramid of the medulla) produces a flaccid paralysis. The reason why pyramidal lesions induce spasticity is that there is *concomitant involvement of extrapyramidal pathways as well*; the responsiveness of the α motor neurons is altered, possibly because they have been released from the inhibition normally exerted by supraspinal levels. Since most of the pyramidal tract is intermingled with extrapyramidal fibres, most pyramidal lesions present as spasticity. The 'up-going toe' of the extensor plantar response (p. 28) remains one of the most important signs in clinical medicine and is taken as evidence of an upper motor neuron lesion.

In the brainstem and spinal cord the motor tracts of each side are quite close together so that a single lesion may easily affect both sides, but in the hemispheres the tracts of the two sides are much farther apart and so unlikely to be damaged together. The single lesion here that does affect both sides together is a parasagittal meningioma pressing on the leg areas of both hemispheres.

Blood supply

The spinal cord is supplied by the (single) anterior and (right and left) posterior spinal arteries which descend from the level of the foramen magnum and form three longitudinal channels from which branches enter the cord. They are supplemented at variable levels by anastomoses with a variable number of radicular arteries.

The **anterior spinal artery** is a midline vessel that lies on the anterior median fissure (Fig. 7.23). It is formed at the foramen magnum by the union of the anterior spinal branch from each vertebral artery. Although it is usually larger than the posterior spinal arteries and runs the whole length of the cord, the anterior spinal may become so small in places, especially in the thoracic region, that it may be considered absent. It supplies the whole cord anterior to the posterior grey columns, i.e. the lateral grey and white columns and the anterior grey and white columns of both sides.

The **posterior spinal artery** on each side arises from the posterior inferior cerebellar or vertebral artery at the foramen magnum. It is usually double, forming longitudinal trunks that run through and behind the posterior nerve rootlets for the whole length of the cord. There is some anastomosis between the vessels of the two sides, with rather scanty connexions with the anterior spinal artery, except at the lower end of the cord where there are often good anastomoses. The

posterior spinal artery supplies the grey and white posterior columns of its own side.

The **radicular arteries** make highly important contributions to reinforce the longitudinal trunks. At one stage during embryonic development every segment of the cord receives a radicular vessel on both sides; they enter through the intervertebral foramina as spinal arteries to penetrate the meninges and run along the nerve roots, and are derived from various parent vessels depending on the level—vertebral, costocervical, posterior intercostal, lumbar, lateral sacral. As fetal growth proceeds, most of the radicular arteries disappear. Those that remain form anastomoses with the anterior and posterior spinal arteries, and are commonly called booster or feeder vessels. Their most characteristic feature is their variability in number and position—one or two, or a dozen or more on either side—and incoming blood from them may flow up and/or down the cord. Because of the frequently small size of the longitudinal trunks, considerable lengths of the cord may be largely dependent on the radicular supply. The largest of the feeder vessels, the *arteria radicularis magna* (of Adamkiewicz), is commonly regarded as being that of the T10 or T11 roots, but although it is slightly commoner at these levels and on the left, it may be anywhere from T7 to L4 level and cannot be relied upon to accompany a low thoracic root. Operations on the vertebral column or adjacent structures (such as aortic aneurysms) that interfere with the parent stems of such radicular vessels may gravely damage the cord.

The anastomotic connexions on the surface of the cord (deep to the pia mater) between the anterior and posterior spinal and radicular vessels provide very small pial arteries that are capable of supplying peripheral areas of the cord. This is important with respect to the lateral corticospinal and anterolateral tracts whose fibres are laminated, with sacral fibres lying nearest to the surface. Interference with the anterior spinal supply may eliminate the function of these tracts, except for the sacral fibres which remain supplied by the pial vessels ('sacral sparing').

As is usual in the body, even when arterial input is by end arteries, the emerging *veins* anastomose freely. The spinal veins form loose-knit plexuses anteriorly and posteriorly. On each side the posterior spinal veins are double, straddling the posterior nerve roots. Both anterior and posterior veins drain along the nerve roots, communicating with the vertebral venous plexuses and (through the intervertebral foramina) with the segmental veins—vertebral in the neck, azygos in the thorax, lumbar in the lumbar region and lateral sacral in the sacral region. At the foramen magnum they communicate with the veins of the medulla.

Spinal cord injury

As examples of applied anatomy, four kinds of spinal cord injury can be considered: complete transection, hemisection, the central cord syndrome, and the anterior spinal artery syndrome.

In *complete transection* there is loss of movement and all sensation below the level of the injured segment. The paralysis, which is at first flaccid, becomes spastic after a few weeks, and bladder and rectal sphincter control is lost, although reflex emptying will occur provided the sacral part of the cord is intact. In lesions above T10 segment there is no effective cough because of abdominal and lower intercostal paralysis. In suspected transection, examination for sensation in the perianal skin will establish whether or not there is conduction throughout the length of the cord. Perianal pinprick will also establish whether the anal reflex is intact (p. 29).

In *hemisection* (Brown-Séquard syndrome) there is paralysis and loss of touch and kinaesthetic sense below the level of the lesion on the same side (lateral corticospinal tract and posterior column interruption), and loss of pain and temperature sensation on the opposite side (because of interruption of the crossed anterolateral tract).

In the *central cord syndrome*, commonly due to a crush injury (without transection) following a sudden hyperextension of the cervical spine, there is flaccid (lower motor neuron) paralysis and loss of pain and temperature sensation in the upper limbs (due to anterior horn damage and interruption of the more deeply placed cervical fibres of the anterolateral tracts). The lower limbs may show spasticity if the lumbar fibres of the lateral corticospinal tract are involved (the sacral fibres are more superficial).

In the *anterior spinal artery syndrome*, the posterior white columns (and therefore touch sensation) remain intact, but most of the rest of the cord below the level of the lesion is affected with loss of all motor and sensory functions, except perhaps for the 'sacral sparing' discussed above.

PART 5

DEVELOPMENT OF THE SPINAL CORD AND BRAINSTEM NUCLEI

The cranial end of the neural tube (p. 35) becomes dilated into vesicles and its walls thicken by proliferation of cells; the cerebral hemispheres, brainstem, and

cerebellum are so developed. More caudally the neural tube enlarges in a simple manner by proliferation of cells, to form the spinal cord. In all regions these proliferating cells arrange themselves regularly in *functional groups*. Attention is focused here on the development of the nuclei in the brainstem, in order to explain that, despite their apparent random arrangement as seen in cross-sections, there is a logical pattern to their positions that can be correlated with the rather simpler disposition of cell groups in the spinal cord.

SPINAL CORD

The central canal, relatively very large at first, is not rounded in cross-section, but is projected laterally into a groove on the inner wall of the spinal cord, as the **sulcus limitans** (Fig. 7.37A). The inner wall of the spinal cord is separated by the sulcus limitans into a dorsal alar lamina and a ventral basal lamina. The **alar lamina** contains sensory (afferent) cells and the **basal lamina** contains motor (efferent) cells. In each lamina the cells are of two kinds; near the sulcus limitans lie the autonomic (**visceral**) cells, while further away lie the body wall and limb (**somatic**) cells (Fig. 7.37A).

BRAINSTEM

A similar arrangement holds in the brainstem as in the spinal cord. But here a third type of cell appears in each lamina, namely the **branchial** afferent and efferent cells of cranial nerves supplying the derivatives of the branchial arches (p. 37). These branchial cells theoretically lie between the autonomic and somatic cells of each lamina. They are the central cell stations of the nerves of the pharyngeal arches (trigeminal, facial, glossopharyngeal and vagus). Unfortunately the branchial group or column is sometimes known as the *special visceral* group, and must not be confused with the *visceral* group which, to help in distinguishing the two, should then be called *general visceral*. It is best to stick to the adjective branchial and so avoid confusion.

In the **fourth ventricle** the central canal is opened out, and basal and alar laminae lie roughly in the same plane; the dorsal afferent and ventral efferent cells here become lateral and medial respectively. The order of the cell groups is similar, but migration of certain cell groups (neurobiotaxis) in the developing brainstem alters, in places, the relatively simple basic arrangement.

Motor nuclei of the brainstem

The motor nuclei are arranged according to the type of

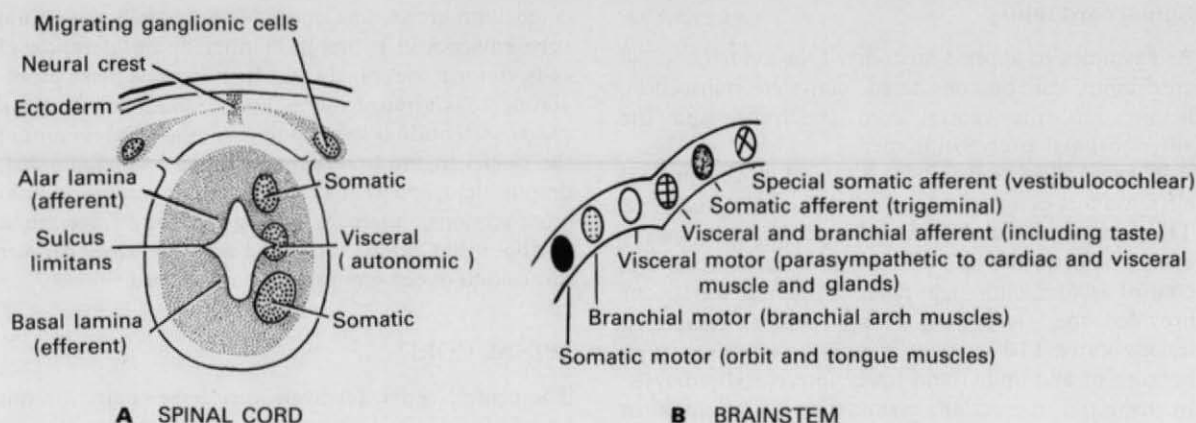


Fig. 7.37 Cell groups of the spinal cord and brainstem. **A** In the developing spinal cord, where motor cells are ventral and sensory cells dorsal with autonomic cells in between. **B** In the brainstem (floor of the fourth ventricle) which resembles an 'opened out' spinal cord, with motor cells now lying medially and sensory cells laterally with autonomic cells in between.

muscle they supply (Fig. 7.37B). The ordinary skeletal muscle of the head (*somatic* muscle) consists of the muscles of the orbit and the muscles of the tongue. In line with the anterior horn cells of the spinal cord, the brainstem nuclei supplying these muscles (*oculomotor*, *trochlear*, *abducent* and *hypoglossal*) lie near the midline ventral to the 'central canal' (i.e. ventral to the aqueduct or floor of the fourth ventricle as the case may be).

Developed from the region of the embryonic pharynx are the striated muscles of mastication, of the face, and of the pharynx and larynx. Their motor nuclei (*branchial*) lie slightly more laterally: the *motor nucleus of the trigeminal nerve*, the *facial nucleus* and the *nucleus ambiguus* (for the glossopharyngeal and vagus nerves and the cranial part of the accessory nerve).

The *visceral* or parasympathetic motor nuclei are represented by the *accessory oculomotor* (Edinger-Westphal) nucleus, the *salivary nucleus* (whose secretomotor fibres join the nervus intermedius part of the facial nerve and the glossopharyngeal nerve), and the *dorsal motor nucleus of the vagus* (for cardiac muscle and the smooth muscle of the alimentary tract).

The above basic arrangement is altered somewhat by medial migration of the Edinger-Westphal nucleus cranial to the somatic part of the oculomotor nucleus, and by lateral migration of the nucleus ambiguus, but in general the three lines of nuclei retain their embryonic relationships (Fig. 7.38).

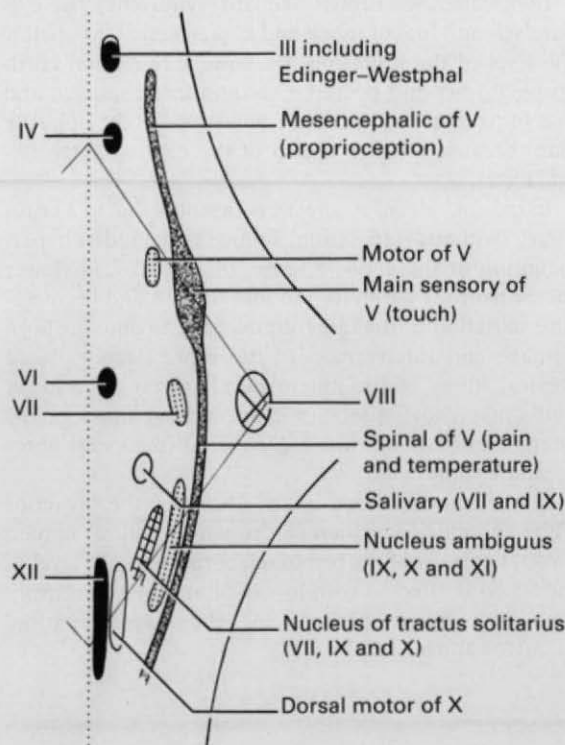


Fig. 7.38 Sites of cranial nerve nuclei in the right half of the brainstem. See text for the correlation between the information in this diagram with that in Figure 7.37B.

Afferent nuclei of the brainstem

These follow the general plan outlined above, and from medial to lateral form *visceral*, *branchial* and *somatic*

afferent groups (the reverse order of the motor efferent columns). But unlike the motor groups, which consist of interrupted columns forming individual nuclei, each of these afferent 'columns' consists of only a single

nuclear mass (Fig. 7.38). The *visceral* and *branchial* afferent cell groups appear to have merged as the *nucleus of the tractus solitarius*, which receives not only taste (branchial) fibres from the facial, glossopharyngeal and vagus nerves but also many visceral afferents from the heart, lungs and viscera from the glossopharyngeal and vagus nerves. (Previously the dorsal nucleus of the vagus was considered to be a mixed nucleus with afferent cell bodies as well as motor cells, but recent authorities suggest that the vagal nucleus itself is purely motor.) The *somatic* afferent column is represented by the *sensory nuclei of the trigeminal nerve*, really one elongated nucleus with different functions at different levels—proprioceptive in the mesencephalic part, touch in the upper pontine part (main sensory nucleus), and pain and temperature in the lower pons and medulla (spinal nucleus). The brainstem has a fourth column of sensory nuclei that has no counterpart in the spinal cord; these are the *cochlear* and *vestibular nuclei* of the vestibulocochlear nerve, and they form a *special somatic* afferent group lying farthest laterally.

PART 6

SUMMARY OF CRANIAL NERVES

The local features of the cranial nerves have been noted in the regions already studied, but it is useful to summarize each nerve. The following account merely brings into continuity the features already seen in the various regions. When reading this, refer to the summary of cranial nerve *nuclei* on page 614.

The first two cranial nerves are not really nerves, but rather outdrawn parts of the central nervous system. Only the peripherally scattered bipolar nerve cells correspond with an ordinary nerve. They are sensory, so in each case it is logical to follow the neurons from the localized periphery to their central connexions. However, for the widely distributed sensory nerves of the brainstem this is not practicable, and it is easier to trace the trigeminal, glossopharyngeal and vagus nerves from their brainstem nuclei to the periphery, just as is done with the motor nerves.

The origin, course and distribution of these cranial nerves stand in increasing clinical importance. Knowledge of the nucleus matters least, of the course matters much more, and of the distribution is most important of all (what is lost if the nerve is lost?).

A scheme that takes note of specific landmarks is desirable, and the following summaries of the cranial nerves are based on this uniform pattern:

(1) Origin, i.e. the nucleus. Its position and the nature of its cell bodies. (The cranial nuclei are listed together on p. 614).

(2) Transit of brainstem—any special features.

(3) Point of attachment to surface of brainstem.

(4) Course through the basal cistern of cerebrospinal fluid.

(5) Point of simultaneous perforation of arachnoid and dura mater (the ganglia of sensory nerves usually lie just beyond this).

(6) point of bony exit from skull, with details of its course between dura mater and bone (not applicable to the last four pairs, which pierce dura mater and bone in the same place).

(7) Extracranial course and distribution. Here it is best to trace the nerve to its terminal destination and *afterwards* recount the details of its branches in their proper order (not applicable to the facial nerve, which radiates from the parotid gland).

OLFACTORY NERVE (I)

From the neuroepithelium in the upper part of the nose trace the two neurons to the olfactory cortex. The first neurons are scattered **bipolar cells** in the neuroepithelium—a unique occurrence. Their central processes gather themselves into nearly 20 olfactory nerve filaments that pass through foramina in the cribriform plate of the ethmoid bone and here pierce the dura and arachnoid mater of the anterior cranial fossa. They enter the olfactory bulb to synapse on the **mitral cells** (second neuron) whose central processes pass in the olfactory tract to the region of the anterior perforated substance and the uncus (p. 581). The arrangement is unique and 'primitive'—the second order neuron directly activates the conscious cortex, by-passing the thalamus. Other olfactory pathways, by polysynaptic junctions, activate hypothalamic and brainstem nuclei (as is the case with all sensory pathways) for visceral and somatic effects, distinct from conscious appreciation.

OPTIC NERVE (II)

From the neuroepithelium in the retina trace the neurons centrally. The rods and cones, near the choroidal surface of the retina, activate the **bipolar cells** of the retina; these are the first sensory neurons. Their central processes synapse on the large **ganglion cells** that lie scattered on the vitreous surface of the retina. The central processes of these second neurons form the optic nerve fibres; they converge to the optic disc and enter the dura and arachnoid mater there. They pass in the optic nerve up to the chiasma where

the nasal fibres from each retina decussate. From the chiasma the optic tract passes around the midbrain (cerebral peduncle) to three destinations: (1) the lateral geniculate body (thalamus) for relay to the visual cortex, (2) the pretectal nuclei for pupil constriction to light, and (3) the superior colliculus for body reflexes to light.

The **visual pathway** is that part of the optic tract which reaches the **lateral geniculate body** of the thalamus (Fig. 7.8). Here the temporal fibres relay on layers 2, 3 and 5 while the crossed nasal fibres do so on layers 1, 4 and 6. From the lateral geniculate body fibres of the third neurons pass through the retrolentiform part of the internal capsule and backwards by the optic radiation to the visual (striate) cortex on the medial surface of the cerebral hemisphere (p. 587). In the visual cortex the macula is represented posteriorly. More peripheral parts of the retina register more anteriorly.

The **pupillary light reflex** and the **accommodation-convergence reflex** are described on page 518, and general light reflexes on page 588.

OCULOMOTOR NERVE (III)

The **oculomotor nucleus** lies in the midbrain at the level of the superior colliculi, near the midline, in the grey matter in the floor of the aqueduct. It is *somatic* (motor to striated ocular muscles) and *visceral* (motor to smooth muscle in the eye) and this latter, the Edinger-Westphal or *accessory oculomotor nucleus*, lies cranial to the somatic nucleus. The fibres (about 24 000) traverse the brainstem with a lateral convexity, passing through the red nucleus and the substantia nigra (Fig. 7.25).

The nerve is attached to the medial surface of the base of the cerebral peduncle near the midline, just above the pons. The nerve is straight and has a gentle downward slope. It passes forwards between the posterior cerebral and superior cerebellar branches of the basilar artery, then below and lateral to the posterior communicating artery and just below the free margin of the tentorium cerebelli, traversing the interpeduncular cistern below the floor of the third ventricle (Fig. 7.23). Lying below the optic tract it pierces arachnoid and dura mater of the roof of the cavernous sinus just behind the upward bend of the internal carotid artery (Fig. 6.47, p. 510).

Still straight and sloping downwards it is attached to the lateral wall of the cavernous sinus above the abducent nerve. It slants down medial to the trochlear nerve and the ophthalmic branch of the trigeminal (Fig. 6.93, p. 565). It picks up some sympathetic fibres

that peel off the internal carotid plexus—these are for the smooth-muscle part of levator palpebrae superioris. At the anterior pole of the cavernous sinus it splits into a superior and an inferior division and immediately enters the tendinous ring at the medial end of the superior orbital fissure. This takes it inside the cone of ocular muscles, with the nasociliary nerve between its divisions and the abducent nerve below it (Fig. 6.20, p. 470).

The **superior division** passes up to enter the ocular surface of superior rectus one-third of the way along. It supplies this muscle and passes on to levator palpebrae superioris. The sympathetic fibres supply the visceral muscle part of levator (their loss accounts for the partial ptosis characteristic of Horner's syndrome—p. 519).

The **inferior division** breaks up quickly into three branches. One supplies medial rectus and another inferior rectus; each of these enters the ocular surface of its muscle one-third of the way along. The third branch, longer, is the nerve to the inferior oblique and passes forwards into the ocular surface of that muscle (Fig. 6.93, p. 565). All the Edinger-Westphal fibres are in the proximal part of this branch. They leave it to enter the ciliary ganglion, where they relay. The cell bodies of the ciliary ganglion supply, through the short ciliary nerves, the sphincter pupillae (for pupil constriction) and the ciliary muscle (for accommodation). Some afferent fibres (passing through the ganglion without relay) supply the cornea.

TROCHLEAR NERVE (IV)

The nucleus is in the midbrain at the level of the inferior colliculi. It is somatic (for the superior oblique muscle) and lies near the midline in the floor of the aqueduct (Fig. 7.26). The fibres (about 3400) *decussate* completely dorsal to the aqueduct. This is unique but the significance is not understood.

The nerve emerges dorsally near the midline behind the inferior colliculus through the apex of the superior medullary velum (Fig. 7.24). Thence it passes around the midbrain just below the free edge of the tentorium cerebelli and runs between the posterior cerebral and superior cerebellar arteries (Fig. 7.23). Clinging to the under surface of the free edge of the tentorium cerebelli it is directed thereby to the roof of the cavernous sinus, piercing the arachnoid and dura (behind the oculomotor nerve) where the free and attached margins of the tentorium cross. Running forwards in the lateral wall of the cavernous sinus below the third nerve it is then crossed medially by it and so becomes the uppermost nerve in the anterior end of the sinus. It enters the superior orbital fissure lateral to the tendinous ring and

passes over levator palpebrae superioris to enter the orbital surface of the superior oblique one-third of the way along the muscle (Fig. 6.47A, p. 510).

TRIGEMINAL NERVE (V)

This is both motor and sensory. The **motor nucleus** is in the upper pons (Fig. 7.27). It is *branchial*, for the muscles of the first branchial arch. It is thus off centre, and lies deep beneath the floor of the fourth ventricle. The **sensory nucleus** is divided into three functionally different parts, but all *somatic*, extending in continuity throughout the whole length of the brainstem and descending into the upper two or three segments of the spinal cord. The **mesencephalic nucleus** extends through the whole length of the midbrain, wherein it lies lateral to the aqueduct, in the central grey matter. It is unique in that its cell bodies are those of the first order neurons; their peripheral processes have passed straight through the trigeminal ganglion. They mediate proprioceptive impulses from the fifth nerve muscles and also from those supplied by the oculomotor, trochlear, abducent and facial nerves and (probably) the hypoglossal nerve. The **main sensory nucleus** is in the upper pons lateral to the motor nucleus and ventral to the superior cerebellar peduncle. It consists of second order cell bodies which mediate sensations of touch from the whole trigeminal territory via the first order neurons whose cell bodies are in the trigeminal ganglion. The **spinal nucleus** is the name given to the column of second order cell bodies that extends from the lower pons through the whole medulla, becoming continuous at the lower end with the gelatinous substance of the spinal cord as far as the third cervical segment. It mediates pain and temperature sensations. Although it is usually stated that pain fibres register in this nucleus in an upside-down manner, with the fibres from the ophthalmic division synapsing with cells in the lowest part, those of the mandibular division going to the uppermost part and maxillary fibres in between, clinical observations indicate that the projection to the nucleus is from an 'onion-skin' pattern of facial supply, working backwards from the mouth (Fig. 6.13B, p. 451).

The fibres that reach the main sensory and spinal nuclei come from cell bodies in the **trigeminal ganglion**. Together with the direct fibres that reach the mesencephalic nucleus they form a single, large, sensory root attached to the pons, well lateral and just above centre. The motor root emerges separately, slightly cranial and medial to its companion (Fig. 7.22, p. 604). Together they pass, below the tentorium cerebelli, to the mouth of the trigeminal cave (Fig. 6.94, p. 566). This is

a tubular prolongation of arachnoid-lined fibrous dura mater around the sensory and motor roots, and it crosses the upper border of the petrous bone near its apex, i.e. it passes from the posterior into the middle cranial fossa. The dural sheath containing the two nerve roots passes forwards, peeling apart the two layers of dura that floor the middle cranial fossa, just lateral to where the same two layers peel apart to enclose the cavernous sinus. The sensory root then expands into the large, flat, crescentic *trigeminal ganglion*; the motor root remains separate. The dural sheath obliterates the subarachnoid space by fusing with the pia mater halfway along the ganglion; this is the anterior extremity of the trigeminal cave (Fig. 6.93, p. 565). The posterior half of the ganglion and both roots are thus bathed in cerebrospinal fluid. The anterior half of the ganglion, beyond the subarachnoid space, gives off its three sensory divisions, ophthalmic, maxillary and mandibular. The first two pass forwards in the lateral wall of the cavernous sinus; they are wholly sensory. The mandibular division, likewise sensory, passes straight down from the lower part of the ganglion to the foramen ovale; here it is joined by the motor root.

Ophthalmic nerve

This is the nerve of the frontonasal process (p. 41 and Fig. 1.37, p. 42). Leaving the upper part of the ganglion the ophthalmic division runs forward in the lateral wall of the cavernous sinus below the trochlear nerve. Here it picks up sympathetic fibres from the cavernous plexus; these are for the dilator pupillae muscle. At the anterior end of the cavernous sinus it gives off meningeal branches, the *tentorial nerves*, which supply all the supratentorial dura mater except that in the bony floor of the middle cranial fossa. Finally it breaks into three branches that pass through the superior orbital fissure—the lacrimal, frontal and nasociliary nerves (Fig. 6.93, p. 565; Fig. 6.20, p. 470).

The **lacrimal nerve**, passing lateral to the tendinous ring, proceeds along the upper part of the lateral wall of the orbit, there picking up a secretomotor branch from the zygomatic nerve which it gives to the lacrimal gland. It is sensory to a fingertip area of skin at the lateral end of the upper eyelid (Fig. 6.13A, p. 451) and to both palpebral and ocular surfaces of the corresponding conjunctiva.

The **frontal nerve** leaves the cavernous sinus to traverse the superior orbital fissure just lateral to the tendinous ring, bunched together between the lacrimal and trochlear nerves. A large nerve, it runs forward in contact with orbital periosteum above levator palpebrae superioris (Fig. 6.47A, p. 510). Just behind the superior

orbital margin it divides into a large supraorbital and a small supratrochlear branch (Fig. 6.13A, p. 451). The *supraorbital nerve* supplies the frontal sinus, notches or perforates the orbital margin, supplies the upper eyelid (skin and both surfaces of conjunctiva), all the forehead except a central strip, and the frontal scalp up to the vertex. The *supratrochlear nerve* supplies the upper lid and conjunctiva and a narrow strip of forehead skin alongside the midline. It scarcely extends beyond the hairline, where the two supraorbital nerves meet each other.

The **nasociliary nerve** is sensory to the whole eyeball, to the paranasal sinuses along the medial wall of the orbit, to some mucous membrane of the nasal cavity and to the skin of the external nose. It carries hitch-hiking sympathetic fibres for the dilator pupillae muscle and changes its name twice, first to anterior ethmoidal and then to external nasal.

The nerve leaves the cavernous sinus and enters the tendinous ring between the two divisions of the oculomotor nerve. It passes straight forwards into the cone of muscles above the optic nerve and along the medial wall of the orbit, below the superior oblique and above the medial rectus. It then passes into the anterior ethmoidal foramen, so becoming the *anterior ethmoidal nerve* (Fig. 6.19, p. 468). Running obliquely forwards it is in the roof of the middle and anterior ethmoidal air cells, supplying their mucous membranes. It passes on to the cribriform plate, between the two layers of dura (Fig. 6.89, p. 561), thus making a very brief appearance in the anterior cranial fossa, and descends through the slit alongside the crista galli into the roof of the nose. It straddles the nose, supplying the anterosuperior quadrant of the lateral wall and the anterosuperior half of the nasal septum. It then continues as the *external nasal nerve*, to notch the nasal bone and supply the skin over the external nasal cartilages, down to the tip of the nose.

The *infratrochlear nerve* branches off the nasociliary just before the latter enters the anterior ethmoidal foramen, and continues forward below the trochlea of the superior oblique tendon, supplies skin and conjunctiva of the medial end of the upper eyelid and ends on the skin over the bridge of the nose.

The *posterior ethmoidal nerve* branches off the nasociliary proximal to the infratrochlear nerve, enters the posterior ethmoidal foramen and supplies the posterior ethmoidal air cells and the adjacent sphenoidal sinus. It does not reach the nasal cavity, and is often very small or even absent.

Near the back of the orbit the nasociliary nerve gives off the communicating branch to the ciliary ganglion (Fig. 6.93, p. 565) and the long ciliary nerves. The *communicating branch* is the sensory root of the

ganglion; its fibres pass through the ganglion and via the 8–10 short ciliary nerves (which are branches from the ganglion also conveying postganglionic parasympathetic fibres to the ciliary muscle and sphincter pupillae) to provide sensory fibres to the eye including the cornea (but not the conjunctiva). The *long ciliary nerves*, usually two, run forward to enter the sclera independently. They carry sympathetic fibres (picked up by the ophthalmic nerve in the cavernous sinus) to the dilator pupillae muscle and (like the short ciliary nerves) are also sensory to the eye, including the cornea (but not the conjunctiva).

Maxillary nerve

This is the nerve of the maxillary process that differentiates from the first pharyngeal arch (p. 38). Leaving the middle part of the trigeminal ganglion the nerve runs forward in the lateral wall of the cavernous sinus below the ophthalmic nerve. The lateral wall here fuses with the outer layer of dura mater at the lateral margin of the foramen rotundum, and so the maxillary nerve is directed through the foramen into the upper part of the pterygopalatine fossa (Fig. 6.93, p. 565). It has a short course, below the roof of the fossa, to the inferior orbital fissure where it turns laterally for a centimetre or so, becoming the **infraorbital nerve** which enters the infraorbital groove and canal, finally emerging on the face through the infraorbital foramen.

Among the most important structures supplied by the nerve are the nasal mucosa, palate, upper teeth, lacrimal gland and the skin of the face between the eye and mouth.

A small meningeal branch (*middle meningeal nerve*) supplies the dura mater of the anterior half of the middle cranial fossa.

The **ganglionic branches** form the connexion between the maxillary nerve and the pterygopalatine ganglion (Fig. 6.19, p. 468); despite the official plural, the connexion is a single stout trunk that passes downwards and medially to the ganglion. Most of the fibres of the trunk pass through the ganglion into its branches, where they mingle with the postganglionic fibres of the greater petrosal and deep petrosal nerves (i.e. fibres of the nerve of the pterygoid canal — p. 468).

The **branches of the ganglion** (which are not the same as the ganglionic branches) can be classified as nasal (nasopalatine and posterior superior nasal), palatine (greater and lesser), pharyngeal and orbital according to their destination.

The *nasopalatine nerve* (long sphenopalatine) enters the sphenopalatine foramen, crosses the roof of the nose and slopes down along the nasal septum,

supplying its posteroinferior half. It goes through the incisive canal and fossa into the hard palate and supplies the gum behind the two incisor teeth.

The *posterior superior lateral and medial nasal nerves* enter the sphenopalatine foramen and supply the posterosuperior quadrant of the lateral wall of the nose and nasal septum respectively.

The *greater palatine nerve* runs down in the greater palatine canal, between the perpendicular plate of the palatine bone and the body of the maxilla (Fig. 6.18, p. 567). Multiple branches supply the posteroinferior quadrant of the lateral wall of the nose and the adjacent floor of the nose; others supply the maxillary sinus nearby. The nerve emerges from the greater palatine foramen and supplies all the hard palate except the incisor gum.

The *lesser palatine nerves* descend through the lesser palatine foramina in the palatine bone and pass back to supply the mucous membrane on both surfaces of the soft palate and on the tonsil.

The *pharyngeal branch* passes back through the palatovaginal canal to supply the mucous membrane of the nasopharynx down to the level of the opening of the auditory tube and possibly part of the tubal mucosa.

The **zygomatic nerve** arises from the maxillary in the pterygopalatine fossa. It enters the inferior orbital fissure and runs along the lower part of the lateral wall of the orbit. It carries the postganglionic secretomotor fibres for the lacrimal gland. These leave the zygomatic nerve and go up the lateral wall of the orbit to join the lacrimal nerve. The zygomatic nerve itself enters the zygomatic bone and there divides into two branches. The *zygomaticofacial nerve* perforates the facial surface of the zygomatic bone and supplies the skin over the bone. The *zygomaticotemporal nerve* perforates the temporal surface of the zygomatic bone, pierces the temporalis fascia, and supplies skin above the zygomatic arch (the 'hairless skin of the temple' Fig. 6.13A, p. 451).

The **posterior superior alveolar nerve** (posterior superior dental) begins as a single branch of the maxillary in the pterygopalatine fossa but quickly divides into three which emerge through the pterygomaxillary fissure. Two enter the posterior wall of the maxilla above the tuberosity. They supply mucous membrane of the maxillary sinus and the three molar teeth (except the anterior buccal root of the first molar). The third stays outside the maxilla, pierces the buccinator, and supplies the gum of the vestibule alongside the three molar teeth.

The **infraorbital nerve**, the changed name of the maxillary when in the inferior orbital fissure, passes forward along the floor of the orbit, sinks into a groove, then enters a canal and emerges on the face through the

infraorbital foramen. It supplies multiple small branches through the orbital surface of the maxilla to the maxillary sinus. In the infraorbital groove it gives off the *middle superior alveolar nerve*. This runs down, supplying adjacent mucosa of the maxillary sinus, to supply the two premolar teeth and the anterior buccal root of the first molar. The infraorbital nerve gives off, in the infraorbital canal, the *anterior superior alveolar nerve* (Fig. 6.23, p. 475). This goes lateral, then turns inferior, to the infraorbital canal, supplies the maxillary sinus, the canine and the two incisors, and reaches the anterior inferior quadrant of the lateral wall of the nose (including the nasolacrimal duct) and the adjacent floor of the nose. It ends on the nasal septum.

Emerging on the face the infraorbital nerve lies between levator labii superioris and levator anguli oris. It has many communications with local branches of the facial nerve; these are for the proprioceptive supply of the nearby facial muscles. It is distributed in three groups of branches (Fig. 6.13A, p. 451). The *palpebral branches* supply the skin of the lower lid and both surfaces of the conjunctiva. The *nasal branches* supply a small strip of skin along the external nose. The *labial branches* supply the skin and mucous membrane of the whole upper lip and also the adjacent gum: that is, from the midline to include the gum of the second premolar tooth.

Mandibular nerve

This is the nerve of the first (mandibular) pharyngeal arch. It is a very short nerve, soon dividing into a sheaf of branches. Leaving the inferior part of the ganglion, it passes down to the foramen ovale (Fig. 6.89, p. 561). It is accompanied by the small motor root of the trigeminal nerve which passes beneath the ganglion and joins the sensory root at the foramen ovale. The mixed nerve then passes from the foramen into the infratemporal fossa, between the upper head of the lateral pterygoid and tensor palati (which lies on the side wall of the nasopharynx). After 4 or 5 mm the nerve divides into a 'cat of nine tails'. These branches consist of an anterior group (all motor except one) and a posterior group (all sensory except one small branch).

There are two branches from the short trunk before it breaks up. A **meningeal branch** (nervus spinosus) passes up through the foramen ovale (sometimes through the foramen spinosum); here it supplies the cartilaginous part of the auditory tube. In the middle fossa it supplies the dura mater in the posterior half thereof, then passes between the squamous and petrous parts of the temporal bone to supply the mastoid antrum and the mastoid air cells that extend from it. It is the nerve of the first pharyngeal pouch.

The **nerve to the medial pterygoid** sinks into the deep surface of the muscle. It has a branch that passes close to the otic ganglion and supplies the two tensor muscles, tensor palati and tensor tympani.

Anterior branches. The anterior leash of branches consists of the following six:

Two **nerves to the lateral pterygoid**, one to each head.

Two **deep temporal nerves**. These pass above the upper head of the lateral pterygoid, turn above the infratemporal crest, and sink into the deep surface of temporalis.

The **nerve to masseter** likewise passes above the upper head of the lateral pterygoid, proceeds laterally behind temporalis and through the mandibular notch to sink into masseter. It gives a branch to the mandibular joint (Hilton's law).

The **buccal nerve** is the only sensory branch of the anterior group and is the only nerve to pass between the two heads of the lateral pterygoid. It carries sometimes a *middle temporal nerve* that enters the deep surface of temporalis. The buccal nerve passes down, deep to temporalis, on the lower head of lateral pterygoid. It reaches the buccinator (Fig. 6.15, p. 458), and gives off here a cutaneous branch which supplies a thumb-print area of skin over the soft cheek immediately below the zygomatic bone (Fig. 6.13A, p. 451). The nerve then pierces the buccinator and supplies the mucous membrane adherent to the deep surface of the muscle and ends by supplying the vestibular gum of the three mandibular molar teeth. The buccal nerve carries secretomotor fibres from the otic ganglion; they are for the molar and buccal glands.

Posterior branches. The posterior branches are three in number, and are all sensory except the mylohyoid branch of the inferior alveolar nerve.

The **auriculotemporal nerve** has two roots that pass back around the middle meningeal artery. The nerve picks up postganglionic secretomotor fibres from the otic ganglion; these are for the parotid gland. It passes back deep to the neck of the mandible, and gives the major sensory supply to the mandibular joint. Curving around the neck of the mandible it supplies the parotid gland with sensory fibres and the secretomotor fibres it picked up from the otic ganglion. The nerve now divides into its terminal branches. The *auricular branch* supplies the external acoustic meatus and the external surface of the auricle above this. The *temporal branch* runs up over the root of the zygomatic process of the temporal bone, behind the superficial temporal vessels, and supplies the hairy skin of the scalp (the hair that first turns grey).

The **inferior alveolar nerve** (inferior dental) passes

down deep to the lower head of the lateral pterygoid (Fig. 6.15, p. 458), and lies on the medial pterygoid between the mandible and the sphenomandibular ligament. It enters the mandibular foramen in front of the inferior alveolar artery and vein. Here it gives off the *nerve to mylohyoid*. This is the only motor part of the posterior branches of the mandibular nerve; it pierces the sphenomandibular ligament, lies in the gutter between the ramus and the medial pterygoid, then lies on the mylohyoid groove made by its accompanying small vessels (Fig. 6.26, p. 486). The mylohyoid nerve passes forwards down into the neck (i.e. below mylohyoid muscle) and runs between mylohyoid and the anterior belly of the digastric, supplying both these muscles. It is accompanied here by the submental branches of the facial artery and vein.

The inferior alveolar nerve runs forwards in the mandibular canal and supplies the posterior five teeth (three molars and two premolars). Then it divides into its two terminal branches. The *incisive branch* goes on to supply the remaining three teeth (canine and both incisors) and overlaps to the opposite central incisor. The *mental nerve* passes from the mental foramen to supply the lower lip (both surfaces) and the adjacent gum, which is from the midline to include the second premolar gum. It carries a few fibres from the otic ganglion to the labial glands of the lower lip.

The **lingual nerve** is joined by the chorda tympani about 2 cm below the base of the skull, deep to the lower border of the lateral pterygoid muscle. It curves down on the medial pterygoid about 1 cm in front of the inferior alveolar nerve (Fig. 6.15, p. 458). It then passes under the free lower border of the superior constrictor and goes forward above the mylohyoid muscle (i.e. in the mouth). It grooves the lingual plate of the mandible just below the last molar tooth, and here gives off a *gingival branch* that supplies the lingual gum to the midline (Fig. 6.26, p. 486). Dipping now below the submandibular duct (Fig. 6.17, p. 465) it ascends on hyoglossus to the anterior two-thirds of the tongue, which it supplies with common sensation and taste, the latter mediated by the chorda tympani fibres. The secretomotor fibres of the chorda tympani (nervus intermedius) are given off to the submandibular ganglion, where they relay to the salivary glands in the floor of the mouth cavity. The lingual nerve and no other supplies all the mucous membrane of the floor of the mouth.

ABDUCENT NERVE (VI)

The **abducent nucleus** is in the lower pons (Fig. 7.28). It is *somatic* and lies near the midline of the fourth

ventricle with fibres of the facial nerve overlying it to produce the bulge known as the facial colliculus (Fig. 7.24). The nerve (with about 6600 fibres) emerges at the lower border of the pons, above the pyramid of the medulla (Fig. 7.22). It enters the pontine cistern and turns upwards, between the anterior inferior cerebellar artery and the pons, to pierce the arachnoid and dura mater on the clivus, above the level of the jugular tubercle (Fig. 6.89, p. 561). Running up now between the two layers of the dura it enters the inferior petrosal sinus at the apex of the petrous temporal bone (Fig. 6.94, p. 566). Here it bends forwards under the petroclinoid ligament to enter the cavernous sinus. It passes straight forwards in the sinus, lateral to the S-bend of the internal carotid artery, and reaches the medial end of the superior orbital fissure. It enters the tendinous ring below the inferior division of the oculomotor nerve (Fig. 6.20, p. 470). In the orbit it passes within the cone of muscles to enter the ocular surface of the lateral rectus one-third of the way along the muscle (Fig. 6.47A, p. 510).

FACIAL NERVE (VII)

The **facial nerve** should perhaps be called the *intermediofacial nerve*, to emphasize that the **nervus intermedius** is classified as part of it. The name 'sensory root of the facial nerve' often applied to the nervus intermedius is not entirely appropriate since the root contains visceral efferent fibres as well as afferents. The term facial nerve will no doubt persist because of long usage and the clumsiness of the adjective that might replace it.

The principal component of the facial nerve is the bundle of *branchial motor* fibres supplying muscles derived from the second pharyngeal arch (and sometimes called the motor root). There are also *visceral efferent* fibres for the submandibular and sublingual salivary glands, lacrimal gland and glands of the nose, palate and pharynx; *visceral afferent* fibres from taste buds in the anterior part of the tongue and the soft palate; and a small *somatic afferent* component from the skin of the external acoustic meatus and tympanic membrane.

The facial nucleus containing the branchial efferent cell bodies is deeply situated in the reticular formation of the lower pons (Fig. 7.28). The fibres (about 7000) approach the floor of the fourth ventricle and make a 'knee-bend' on the surface of the abducent nucleus at the facial colliculus, but it is the abducent nucleus deep to them that is responsible for the little hillock. The facial nerve traverses the pons and emerges at its lower border above the olive as the main part (motor root) of

the facial nerve (Fig. 7.22, p. 604). The *visceral motor* (secretomotor) nucleus of the nervus intermedius part is the **superior salivary nucleus**, part of the visceral efferent column and situated adjacent to the (branchial) facial nucleus. The sensory nucleus is the **nucleus of the tractus solitarius** which lies further laterally but mostly in the medulla: it receives the central processes of the taste cell bodies of the geniculate ganglion, but the few sensory fibres from the skin of the external ear whose cell bodies are also in the ganglion pass to **trigeminal nuclei**.

The nervus intermedius passes through the pons and emerges at its lower border, between the pons and the inferior cerebellar peduncle, near the vestibulocochlear nerve (Fig. 7.22). With the main part of the facial nerve it passes laterally in the cerebellopontine angle through the pontine cistern and, with the eighth nerve, they enter the internal acoustic meatus. In the meatus the main part of the facial nerve lies on the upper surface of the eighth nerve, with the nervus intermedius in between. The whole facial nerve passes into the antero-superior quadrant of the meatus (Fig. 6.95, p. 572). Running laterally in the petrous bone, above the vestibule of the internal ear, the two parts of the nerve share a common tube of arachnoid and dura mater. The meninges then fuse with the nerves to make a single trunk, and near the middle ear the nerve makes a sharp posterior bend, the geniculum, which becomes distended due to the presence here of the cells that form the **geniculate ganglion**—the cell bodies of the afferent fibres (Fig. 6.18, p. 467).

The combined nerve runs back in the medial wall of the middle ear, above the promontory and just below the bulge of the lateral semicircular canal. It now curves downwards behind the middle ear, deep to the aditus to the antrum, and passes vertically down the facial canal. After shedding all the hitch-hiking nervus intermedius fibres, the nerve emerges from the stylomastoid foramen, now a purely branchial motor nerve. The face muscles supplied by the facial nerve receive their proprioceptive supply from the cutaneous nerves of the overlying skin (trigeminal nerve branches).

The *intracranial branches* of the facial nerve that arise within the petrous bone include the greater petrosal nerve, tympanic branches, the nerve to stapedius and the chorda tympani.

The **greater petrosal nerve** is a branch of the nervus intermedius, and its greatest importance lies in the fact that it can be said to be the nerve of tear secretion. It is also secretomotor to glands of the palate, pharynx and nose, and has a few taste fibres for the scattered taste buds on the oral surface of the palate. The cell bodies of the taste fibres are in the geniculate

ganglion. The greater petrosal nerve leaves the ganglion and travels forwards and medially at a 45° slant through the petrous bone (Fig. 6.18, p. 467). It emerges and slants forwards in a groove on the petrous bone, between the two layers of the dura mater. Here in the middle cranial fossa it may be pulled on in extradural operations and so cause small haemorrhage or oedema at the geniculate ganglion with consequent pressure on the facial nerve and a temporary facial paresis. The nerve passes beneath the trigeminal ganglion in Meckel's cave and reaches the foramen lacerum. Here it is joined by the deep petrosal nerve (Fig. 6.19, p. 468), which peels off from the sympathetic plexus on the internal carotid artery (the cell bodies of the deep petrosal nerve are in the superior cervical ganglion). The two join and pass forwards through the pterygoid canal. The nerve of the pterygoid canal emerges into the pterygopalatine fossa and enters the pterygopalatine ganglion. Here the secretomotor fibres relay. The taste fibres and the sympathetic fibres pass straight through the ganglion, together with the sensory fibres of the maxillary nerve. Joined by postganglionic secretomotor fibres they innervate the five territories of the ganglion (nasal septum, lateral nasal wall, paranasal sinuses, hard and soft palates, and the nasopharynx). Lacratory postganglionic fibres join the maxillary nerve and enter the orbit in its zygomatic branch (p. 633). They pass up the lateral wall of the orbit to join the lacrimal nerve (from the ophthalmic) and so reach the lacrimal gland.

The small **tympenic branches** are sensory, joining the tympanic plexus (p. 592) in the mucous membrane of the middle ear. Some traverse the tympanic membrane and trespass into auriculotemporal nerve territory on the skin of the external acoustic meatus and pinna. Their chief interest is that their cell bodies are in the geniculate ganglion and, when this is afflicted by herpes, vesicles appear in the area supplied, including the tympanic membrane.

The **nerve to stapedius** is given off in the facial canal and reaches the muscle by a minute canaliculus.

The **chorda tympani** is secretomotor for the salivary glands in the floor of the oral cavity, and also carries the taste fibres for the anterior part of the tongue. All its fibres belong to the nervus intermedius part of the nerve. It leaves the facial nerve in the facial canal 6 mm above the stylomastoid foramen and passes through the posterior wall of the middle ear (Fig. 6.18, p. 467). It is draped over by the mucous membrane as it passes across the pars flaccida of the tympanic membrane and the neck of the malleus. It leaves through the anterior wall of the middle ear, passes through the petrous bone, and emerges at the medial

end of the petrotympanic fissure. Passing down deep to the spine of the sphenoid, which it grooves on its medial side, the nerve slopes forwards to join the lingual nerve just above the lower border of the lateral pterygoid muscle, about 2 cm beneath the skull. By the lingual nerve its taste fibres are taken to the anterior part of the tongue. Its secretomotor fibres relay in the submandibular ganglion and pass to the glands in the floor of the mouth cavity.

The **extracranial branches** include the posterior auricular nerve (for the occipital belly of occipitofrontalis), the nerves to the posterior belly of digastric and stylohyoid, and the five groups of branches for the facial muscles and platysma (p. 449).

VESTIBULOCOCHLEAR NERVE (VIII)

The nerve is wholly sensory (*special somatic*) for sound reception and balance; thus the nuclei lie in the lateral part of the brainstem, in the medulla and encroaching on the pons. It is logical and convenient to trace the nerve from the periphery to its brainstem nuclei, as in studying the first and second cranial nerves (the diffuse peripheral distribution of the sensory fibres in the trigeminal, glossopharyngeal and vagus nerves makes it imperative to trace them in the reverse direction, from the nucleus to the periphery). There are two quite distinct parts of the eighth nerve. From fishes to man sound reception and balance are combined in the one sensory organ (but with quite separate receptors) and in a single cranial nerve; it is a mystery why this should be, or what connexion (if any) sound reception has with balance.

Cochlear nerve

The neuroepithelium for sound reception consists of the hair cells of the spiral organ. The first sensory neuron is bipolar with the cell body in the base of the bony spiral lamina. The cell bodies thus lying in a spiral line are together referred to as the **spiral** or **cochlear ganglion**. Their central processes run along the modiolus of the cochlea and join into many small nerves that pierce dura and arachnoid mater at the base of the modiolus in a spiral pattern (Fig. 6.64, p. 533). This is at the anteroinferior quadrant of the internal acoustic meatus (Fig. 6.95, p. 572). They join together in the subarachnoid space and enter the pontine cistern joined with the vestibular part. The nervus intermedius and the main part of the facial nerve lie in front (Fig. 6.96, p. 573). Together these three pass through the cerebellopontine angle in front of the flocculus of the cerebellum and the lateral aperture of the fourth

ventricle (Fig. 7.22). The eighth nerve (cochlear and vestibular parts bound together) enters the inferior cerebellar peduncle at the lower border of the pons.

The cochlear fibres (about 30 000) relay in the dorsal and ventral **cochlear nuclei** in the inferior cerebellar peduncle. These second order cell bodies send their central processes to cross in the lower pons and turn up as they cross the medial lemniscus, here forming the *trapezoid body* to ascend as the *lateral lemniscus*. Some fibres do not cross but run in the lateral lemniscus of their own side; cochlear representation is largely bilateral. The lateral lemniscus ascends through the tegmentum of the midbrain and some of its fibres relay in the **inferior colliculus** (*for reflex effects of sound*). Tectobulbar and tectospinal tracts activate motor nuclei for head and neck and for body and limb reflex movements (compare with light reflex relay in the superior colliculus). The remainder of the lateral lemniscus relays in the **medial geniculate body** (*for hearing*). This body, though anatomically in the midbrain, is a displaced thalamic nucleus. From here the cell bodies send their processes into the sublentiform part of the internal capsule, forming the auditory radiation which passes to the auditory area of the cortex below and within the lateral sulcus (p. 586).

Although the auditory pathway may be said to consist, like most afferent pathways, of three groups of neurons with cell bodies in the spiral ganglion, cochlear nuclei and medial geniculate body, there may be more depending on the number of intermediate relays; both the trapezoid body and lateral lemniscus have some cell bodies where fibres relay. However, this is of academic rather than clinical interest.

Vestibular nerve

The neuroepithelium consists of the hair cells in the *maculae* of utricle and saccule (for static balance) and the *ampullae* of the semicircular ducts (for kinetic balance). The first neurons emerge from the fundus of the internal acoustic meatus, above and below the horizontal crest (Fig. 6.95, p. 572). From the postero-superior quadrant of the fundus emerges the nerve from anterior and lateral semicircular ducts and the utricle into which they open (Fig. 6.65, p. 533). Through the posteroinferior quadrant comes the lower division of the vestibular nerve, from the saccule. Alongside it, through the foramen singulare, emerges the nerve from the ampulla of the posterior semicircular duct. Having pierced the fibrous dura and arachnoid mater the upper and lower divisions lie in the internal acoustic meatus (Fig. 6.64, p. 533) and are here distended into **vestibular ganglia** by the cell bodies of these first

order neurons. The central processes combine into the vestibular nerve (about 18 000 fibres). This joins the cochlear nerve and passes into the pontine cistern. The vestibular fibres relay in the **vestibular nuclei**, lateral and medial, superior and inferior, in the lateral angle of the fourth ventricle (Fig. 7.28), in both pons and medulla. The nuclei send fibres to the archaocerebellum and, by the medial longitudinal bundle, to the motor nuclei of the brainstem. The *vestibulospinal tract* descends from the lateral vestibular nucleus to anterior horn cells, and is one of the most important extrapyramidal tracts. There appear to be cortical connexions from the vestibular nuclei, by way of bilateral thalamic relay (i.e. medial geniculate body), to the region of the auditory cortex.

GLOSSOPHARYNGEAL NERVE (IX)

This is the nerve of the third branchial arch, with nuclei in the medulla and lowest part of the pons (Fig. 7.38). It is *visceral* as well as *branchial*, and mixed *sensory* and *motor* (i.e. secretomotor). The small number of branchial motor fibres come from the **nucleus ambiguus** in the upper medulla (Fig. 7.29) and supply only stylopharyngeus. The secretomotor fibres come from the **inferior salivary nucleus** in the lowest part of the pons rostral to the dorsal nucleus of the vagus, and supply the parotid gland via the lesser petrosal nerve and the otic ganglion. Taste fibres from the posterior part of the tongue and afferents from carotid sinus and carotid body enter the **nucleus of the tractus solitarius** in the lower medulla, while fibres of ordinary sensation from the tongue, pharynx, palate and tonsil enter the **sensory nuclei of the trigeminal nerve**.

From the above nuclei the fibres reach the surface of the medulla between olive and inferior cerebellar peduncle (Fig. 7.22). In a series of rootlets which join to make a single nerve it emerges in the pontine cistern and runs laterally behind the jugular tubercle of the occipital bone and enters the anterior compartment of the jugular foramen (Fig. 6.96, p. 573). Here it lies lateral to the inferior petrosal sinus; together they are separated from the vagus and accessory nerves by a septum of fibrous dura mater. The glossopharyngeal nerve deeply notches the inferior border of the petrous bone, just below the internal acoustic meatus. Perforating the arachnoid and dura mater the nerve is distended into its elongated *inferior ganglion* (the *superior ganglion* is a small detached part of it); the cell bodies of the nerve's afferent fibres are in these ganglia.

The **tympanic branch** passes into the middle ear through the tympanic canaliculus to form the tympanic plexus, from which emerges the lesser petrosal nerve.

This runs through the foramen ovale (or petrosal foramen) to join the otic ganglion for the supply of the parotid gland.

The **nerve to stylopharyngeus**, given off as the nerve winds round the muscle, is the only muscular branch.

The **carotid sinus nerve** provides vital connexions with autonomic cell groups in the reticular formation.

Pharyngeal branches take part (with the vagus) in forming the pharyngeal plexus; the fibres are afferent, not motor to the muscles.

The **tonsillar branch** provides afferent fibres for the tonsillar mucosa, and the **lingual branch** is sensory to the posterior part of the tongue, with a few secretomotor fibres for lingual glands.

VAGUS NERVE (X)

The nuclei lie in the upper part of the medulla (Fig. 7.29). There are *branchial* and *visceral* fibres that are both *afferent* and *efferent*, and also *somatic afferents*. The branchial motor fibres are from the **nucleus ambiguus** which innervates all the skeletal muscle supplied by the vagus, i.e. the muscles of the pharynx and upper oesophagus, larynx and palate (largely by accessory nerve fibres which join the vagus). The **dorsal motor nucleus of the vagus**, below the vagal trigone in the floor of the fourth ventricle, supplies cardiac muscle and smooth muscle (of bronchi and gut). The **nucleus of the tractus solitarius** receives afferent fibres from the heart and thoracic abdominal viscera for many reflex activities. It also receives a few taste fibres from the epiglottis and perhaps fibres of ordinary sensation from parts of the pharynx and larynx, though it is not certain whether these afferent fibres run instead to the sensory **nuclei of the trigeminal nerve**, which also receives fibres from the small area of skin supplied by the auricular branch of the vagus (over the mastoid process and in the external acoustic meatus).

From the above nuclei the fibres leave the surface of the medulla in a series of rootlets below those of the glossopharyngeal nerve in the sulcus between olive and inferior cerebellar peduncle (Fig. 7.22). These unite into a single nerve that crosses, below the glossopharyngeal and above the accessory nerve rootlets, the basiociput behind the jugular tubercle (Fig. 6.96, p. 573). With the accessory nerve it enters the transverse slit of the middle compartment of the jugular foramen. Here it lies medial to the accessory, and perforates the arachnoid and dura mater. A small **superior ganglion** lies just above the long **inferior ganglion**, which distends the vagus below the skull base. The superior ganglion has cell bodies for the unimportant meningeal and

auricular branches. The inferior ganglion lodges the cell bodies of all the other sensory fibres in the vagus nerve. At the inferior ganglion the accessory nerve gives *all* its nucleus ambiguus fibres to the vagus. This is similar to the motor root of a spinal nerve joining the sensory root just distal to the sensory ganglion. The nucleus ambiguus fibres are wholly motor; they are paid off in the appropriate branches of the vagus to skeletal muscle.

In the neck the vagus lies vertical, like a plumb line, in the carotid sheath, adherent to the internal carotid and then to the common carotid artery, always deep in the gutter between the artery and the internal jugular vein.

The smallest *cervical* branches are the *meningeal*, *auricular* and *carotid body branches*, all afferent.

The **pharyngeal branch** provides both motor and sensory fibres for the pharyngeal plexus, and passes between the internal and external carotid arteries. The **superior laryngeal branch** runs deep to the carotids and divides into the *internal laryngeal nerve*, which pierces the thyrohyoid membrane to supply mucosa in the pharynx and larynx, and the *external laryngeal nerve* which runs to cricothyroid. **Cervical cardiac branches**, upper and lower on the right and lower on the left, join the deep part of the cardiac plexus; the upper one on the right joins the superficial part of the plexus. The **right recurrent laryngeal nerve** hooks under the subclavian artery and runs up at the tracheo-oesophageal border to pass under the inferior constrictor of the pharynx just behind the cricothyroid joint, to supply muscles of the larynx and laryngeal mucosa below the level of the vocal folds.

In the *thorax* the **left recurrent laryngeal nerve** hooks round the ligamentum arteriosum, and pursues a similar but longer course to that on the right. Both vagi and the recurrent laryngeals give *cardiac branches*, and the main nerves themselves give *tracheal* and *oesophageal branches* and form the **oesophageal plexuses** behind the oesophagus.

From the oesophageal plexuses the **anterior** and **posterior vagal trunks** emerge, to enter the abdomen through the oesophageal opening in the diaphragm; their main purpose is to supply the muscle and glands of the stomach from branches which arise in the lesser omentum.

It should be noted here that the branches to the gut and its derivatives are motor to smooth muscle and secretomotor to glands, but do not carry pain fibres. From abdominal viscera these run with sympathetic fibres, but the vagus is sensory to the thoracic viscera (oesophagus, trachea and lungs).

ACCESSORY NERVE (XI)

The accessory nerve has cranial and spinal roots. The **cranial root** really belongs to the vagus and gives all its fibres to it, for the supply of the skeletal muscles of the pharynx and palate. The fibres come from the **nucleus ambiguus** and leave the medulla as a series of rootlets below those of the vagus between the olive and inferior cerebellar peduncle. They unite into the single cranial root, which is joined by the spinal root coming up through the foramen magnum into the pontine cistern.

The **spinal root** is formed by fibres from cell bodies (the 'spinal accessory nucleus') in the **anterior horn** of the upper five or six segments of the cervical cord (mainly 2, 3 and 4). Unlike other anterior horn cell axons, they do not leave the cord via the anterior nerve roots, but emerge as a series of roots from the lateral surface of the cord *behind* the denticulate ligament. Joining together, the roots form a single nerve that passes over the upper tooth of the denticulate ligament to join the cranial root. These two roots have nothing to do with each other and are bound for different destinations. They merely 'join hands' to pass through the jugular foramen together, then part company.

The accessory nerve lies caudal to the vagus on the basiocciput behind the jugular tubercle (Fig. 6.96, p. 573). It passes through the lateral part of the slit-like middle compartment of the jugular foramen, piercing arachnoid and dura mater here. The vagus lies medial to it in the jugular foramen, just in front of the jugular bulb. Outside the skull the accessory gives all its cranial (nucleus ambiguus) fibres to the vagus, and these are distributed by vagal branches to the striated muscle of the soft palate, pharynx and oesophagus, and larynx. The accessory nerve in the neck, wholly motor and wholly spinal now, lies on the internal jugular vein over the lateral mass of the atlas (Fig. 6.16, p. 463); passes into sternocleidomastoid which it supplies, and then descends within the posterior triangle over levator scapulae to supply trapezius by passing into its deep surface (Fig. 6.2, p. 425).

The nucleus ambiguus fibres joining the vagus conform with the regular pattern of mixed (spinal) nerves. They are analagous to the motor root of the trigeminal nerve. The cranial root of the accessory nerve is actually no more than the 'motor root' (to *striated muscle only*) of the vagus. The curious pathway of the spinal fibres in the accessory nerve constitutes a mystery.

HYPOGLOSSAL NERVE (XII)

The **hypoglossal nucleus** is in the medulla. It is *motor* and *somatic*, and thus lies against the midline, in the

hypoglossal trigone in the floor of the fourth ventricle (Fig. 7.24). The fibres pass ventrally through the inferior olivary nucleus and emerge from the surface of the medulla as a vertical line of rootlets between pyramid and olive (Fig. 7.22). These join into two roots that enter the hypoglossal (anterior condylar) canal in the occipital bone (Fig. 6.96, p. 573). They are here separated by a flange of fibrous dura mater that sometimes ossifies. They pass forward above the atlanto-occipital joint and join in the canal, emerging as a single nerve. They pierce the arachnoid and dura mater in the canal.

Examine a skull; note that the exit is deep (i.e. medial and posterior) to the jugular foramen where the glossopharyngeal, vagus and accessory emerge. The hypoglossal nerve from this deep position spirals down and forwards with a lateral convexity that brings it gradually more superficial. It spirals down behind the inferior ganglion of the vagus, then descends behind and around the internal and then the external carotid arteries (Fig. 6.17, p. 465). At this level, below the posterior belly of digastric, it lies on three arteries (occipital, external carotid and lingual) and is very near the skin, covered only by the facial vein beneath the investing layer of deep cervical fascia. This spiral course curves outside the arteries but deep to the veins; it is the pathway of migration of the suboccipital myotomes that form the muscles of the tongue. The hypoglossal nerve now passes forward on hyoglossus deep to mylohyoid (i.e. in the mouth). Running above the greater horn of the hyoid bone it splits up to supply all the intrinsic and extrinsic muscles of the tongue except palatoglossus.

The branches of the hypoglossal nerve (before it reaches the tongue) are all derived from C1 nerve fibres that join the hypoglossal at its exit from the skull. The fibres from the hypoglossal nucleus itself have no supply outside the tongue. The branches derived from C1 fibres must still be classified as branches of the hypoglossal nerve, even though their origins are not from the hypoglossal nucleus.

A very small meningeal branch supplies a ring of dura mater in the posterior cranial fossa beyond the margin of the foramen magnum.

The upper root of the ansa cervicalis (the former descendens hypoglossi) branches off as the hypoglossal nerve curves down between the internal carotid artery and the internal jugular vein. It is joined at a variable level by the lower root of the ansa cervicalis (formerly the descendens cervicalis) derived from C2 and 3 nerves of the cervical plexus. Together these nerves make the **ansa cervicalis**. The ansa lies on the internal jugular vein under cover of sternocleidomastoid embedded in the anterior wall of the carotid sheath. Its

branches supply segmentally sternohyoid (C1, 2, 3), omohyoid (C1, 2, 3) and sternothyroid (C2, 3).

The slender **nerve to thyrohyoid** (C1) comes off as the main nerve lies on the lingual artery. The last branch is the **nerve to geniohyoid** (C1), given off in the mouth, above mylohyoid, and contains the last of the C1 fibres that travel along the hypoglossal nerve.

PART 7

SUMMARY OF CRANIAL NERVE LESIONS

Having relatively short courses, the peripheral parts of cranial nerves are not subject to the kind of injuries that commonly afflict peripheral nerves in the limbs. Those most commonly affected by trauma are the first, second, third, sixth and seventh, but tumours, ischaemia of nerve trunks and aneurysms of adjacent vessels are among the more usual afflictions of these and other cranial nerves. The following account of selected cranial nerve lesions illustrates the more important features of their clinical anatomy.

OLFACTORY NERVE

Head injury may tear olfactory nerve filaments passing through the cribriform plate of the ethmoid, especially if a fracture involves this part of the anterior cranial fossa. If all filaments on one side are torn there will be complete anosmia on that side. Test by closing one nostril (with finger pressure) and sniffing familiar substances like coffee or oranges (not strong irritants). Most deficiencies of smell are due to affections of nasal mucosa rather than neurological disease. Remember that smell is an essential component of taste, and complaints about lack of taste may be due to loss of smell. Olfactory hallucinations, which are usually unpleasant, arise from the uncus of the temporal lobe (the cortical centre for smell).

OPTIC NERVE

Assessment of the visual fields tests the integrity of the visual pathways from retina to cortex, and lesions at different points along the path give rise to characteristic defects, as illustrated in Figure 7.8. The defects are conventionally described with reference to the visual fields and not to the retina; recall, for example, that the left half of the visual field of each eye is represented in the right lateral geniculate body and right visual cortex,

and that the upper part of the visual field is represented in the lateral part of the lateral geniculate body and in the visual cortex below the calcarine sulcus. The numbers below correspond to the sites of the lesions in Figure 7.8A; clinically the commonest lesions are at the chiasma (2) and in the optic radiation (4). The visual field defects are indicated in Figure 7.8B.

(1) A complete lesion of the left optic nerve gives rise to complete blindness in the left eye.

(2) Compression of the optic chiasma, as by a pituitary tumour, causes bitemporal hemianopia (blindness in the temporal half of both visual fields) because the nasal fibres from each retina are interrupted. This effectively narrows the outer part of each visual field, so that the patient complains of bumping into the sides of a doorway or into people on each side.

(3) A lesion of the left optic tract gives a right homonymous hemianopia, due to interruption of fibres from the same (left) sides of both retinas (hence homonymous, meaning same-sided). The field defects are therefore right-sided.

(4) A lesion of the lower fibres in the left optic radiation (as from an abscess in the temporal lobe spreading upwards from the middle ear) causes a right upper quadrantic homonymous hemianopia, because the lower fibres in the optic radiation (from the lower part of the retina) are represented in the upper part of the visual field.

(5) Similar to (4), a lesion of the upper fibres in the left optic radiation (as from a parietal lobe lesion, and in practice very rare) gives a right lower quadrantic homonymous hemianopia.

(6) A lesion of the anterior part of the left visual cortex (as from occlusion of the posterior cerebral artery) gives a right homonymous hemianopia similar to the optic tract lesion in (3), but there is sparing of the macular (central) vision because the most posterior part of the visual cortex at the very tip of the occipital lobe where macular vision is represented is supplied by the middle cerebral artery.

(7) Traumatic damage to the tip of the left occipital lobe, i.e. to the macular area, gives a right homonymous macular defect.

OCULOMOTOR, TROCHLEAR AND ABDUCENT NERVES

Ocular nerve palsies have already been described (p. 516), and the following synopsis is simply a reminder of the major signs that were explained in the original descriptions:

Oculomotor nerve: ptosis. When the lid is lifted up, the

eye is looking down and out. The diplopia disappears on looking outwards. The pupil is dilated and does not react to light or on accommodation; ptosis with a large pupil thus suggests an oculomotor nerve lesion (but with a small pupil suggests Horner's syndrome, p. 519).

Trochlear nerve: the eye cannot look down as far as it should when turned in. The head is tilted towards the opposite shoulder to compensate for extorsion.

Abducent nerve: the eye cannot look out.

TRIGEMINAL NERVE

Affections of the motor part of the fifth nerve, whose fibres run in the mandibular branch, are very unusual. Test for contraction of masseter.

The commonest condition affecting the sensory part of the nerve is trigeminal neuralgia (*tic douloureux*), of unknown cause and characterized by pain in the distribution of the maxillary and/or mandibular branches. The ophthalmic branch is rarely involved and, equally strangely, nor is the complete distribution of the affected main branch. With the maxillary nerve affected the pain is usually felt deeply in the face and nose between the mouth and orbit, and with the mandibular nerve from the mouth up to the ear and the temporal region—but not along the lower part of the mandible or the angle, where the nerve supply is by the great auricular nerve. Injection or electrocoagulation of the trigeminal ganglion may be necessary to abolish the pain.

It should be noted that the sensory distribution of the mandibular nerve extends into the external ear and on to the temporal region via the auriculotemporal branch, and that the ophthalmic nerve distribution stretches from the tip of the nose to the vertex of the skull, well beyond the hairline and as far back as a line drawn upwards from both ears. The appearance of herpetic vesicles on the tip of the nose should be a warning that the cornea may become involved (p. 451).

The afferent side of the corneal reflex (p. 517) depends on the ciliary branches of the nasociliary part of the ophthalmic nerve. Disappearance of the reflex is often the first sign of a lesion of the ophthalmic nerve; test by gently touching the cornea (not the conjunctiva) with cotton wool.

FACIAL NERVE

Facial nerve paralysis is the commonest of all cranial nerve lesions. The usual type (Bell's palsy) is of uncertain aetiology, but is probably a virus infection causing swelling on the nerve in the facial canal just before it emerges from the stylomastoid foramen. There is paralysis of facial muscles giving drooping of the corner of

the mouth, flattening of skin folds and inability to close the eye or wrinkle the forehead on the affected side. Test by asking the patient to show the teeth forcibly, screw up the eyes and wrinkle the forehead; note the asymmetry compared with the unaffected side.

A lesion higher in the facial canal, above the origin of the chorda tympani, will add to the facial paralysis a loss of taste in the anterior part of the tongue. Test by holding the tongue out and applying sweet, sour and salt substances on cotton wool to the sides of the dorsum, asking the patient to point to the appropriate flavour written on a card (and not to speak, since this involves spreading the test substance all over the tongue). The accompanying interference with secretion from the submandibular and sublingual glands is very difficult to detect or test. A lesion higher still, above the origin of the nerve to stapedius, will give hyperacusis.

The above are all lesions of the lower motor neuron (infranuclear). A typical upper motor neuron lesion (supranuclear) paralyzes the lower part of the face but not the upper (forehead and orbicularis oculi) because the upper part of the facial nerve nucleus which innervates the upper musculature is supplied by the cerebral cortex of both sides, whereas the lower part innervating the lower face only receives contralateral cortical fibres (p. 612). However, emotional (as opposed to voluntary) movements of the facial muscles, as in smiling and laughing, are still possible with supranuclear lesions (so presumably there must be alternative pathways through the cerebrum).

VESTIBULOCOCHLEAR NERVE

Acoustic neuromas on the extracerebral part of the eighth nerve are among the commonest intracranial tumours, but other lesions of this nerve are rare. In any loss of hearing, it must be determined whether it is *conduction deafness* from lesions of the external or middle ear, or *nerve deafness* from a cochlear lesion.

The simple tests for hearing involve asking the patient to listen to whispering (repeating what is said), the ticking of a watch, and the rubbing together of a thumb and forefinger (with the opposite ear closed by finger pressure on the tragus, and after examining the external acoustic meatus and tympanic membrane with an auroscope). Both ears are similarly tested. The basis of the two common tuning fork tests is that air conduction, which involves the amplifying effect of the ossicles across the middle ear cavity, is better than solid bone conduction. In Weber's test a vibrating tuning fork is placed on the midline of the forehead; in conduction deafness the sound is heard better in the deaf ear, and

in nerve deafness it is better in the good ear. In Rinne's test the vibrating fork is held on the mastoid process until the sound is no longer heard and then quickly transferred to the external acoustic meatus; in a normal ear or with nerve deafness the sound will be heard again; but in conduction deafness further sound will not be heard. For more precise information audiometric tests are necessary.

Diseases of the internal ear or its central connexions (as in Ménière's disease where there are degenerative changes in the utricle and saccule) form one group of causes of muscular inco-ordination or ataxia (labyrinthine ataxia; the other varieties of ataxia are cerebellar and sensory—p. 624). The semicircular ducts of the vestibular apparatus can be tested with the head in different positions by irrigating the external acoustic meatus alternately with warm (44°C, 110°F) and cool (30°C, 86°F) water (caloric tests); this stimulates convection currents in the endolymph causing vertigo (giddiness) and nystagmus (p. 515). The slow phase of the nystagmus is in the direction of the movement of the endolymph. Cool water irrigation causes nystagmus to the opposite side, warm to the same side. Inner ear disease gives an exaggerated response with the head in a particular position, whereas vestibular nerve damage gives an exaggerated response in any head position. In vestibular nystagmus there is a slow phase towards the stimulated side and a quick return (in contrast to ocular nystagmus in which the oscillatory movements are equal in both directions). The absence of vestibulo-ocular reflexes after irrigation with ice-cold water is one of the criteria of brain death (p. 616).

GLOSSOPHARYNGEAL NERVE

Isolated glossopharyngeal nerve lesions are extremely rare, as the last four cranial nerves are not often damaged and even if they are, they are commonly affected together (e.g. by a posterior cranial fossa tumour). Since the motor part of the glossopharyngeal nerve supplies only one small muscle, stylopharyngeus, it is impossible to test. If necessary, taste sensation on the posterior part of the tongue can be tested.

VAGUS NERVE

Through its pharyngeal and laryngeal branches the motor component of the vagus nerve (nucleus

ambiguus) supplies the pharynx, palate and larynx. Recurrent laryngeal nerve palsies are most commonly due to malignant disease (25%) and surgical damage (20%) during operations on the thyroid gland, neck, oesophagus, heart and lung. Because of its longer course, lesions of the left nerve are much more frequent than those of the right. Test the motor innervation of the vocal cords by listening to the patient's speech and cough and by inspecting the cords through a laryngoscope. Note the presence of any frothy mucus on the paralysed side at the oesophageal opening, suggesting paralysis of cricopharyngeus (if supplied by the recurrent laryngeal nerve), which allows some regurgitation. In a complete unilateral paralysis (p. 504) the cord takes up an intermediate position between full abduction and adduction; the voice is hoarse and the patient cannot cough in the usual explosive manner. In an incomplete lesion the cord takes up an adducted position, i.e. the power of abduction seems to be lost first. Despite several theories, there is no universally acceptable explanation why this should be so.

High lesions of the vagus nerve which affect the pharyngeal and superior laryngeal as well as the recurrent laryngeal branches cause difficulty in swallowing as well as vocal cord defects. The motor innervation of the soft palate can be tested by asking the patient to say a prolonged 'Ah' and observing the upward palatal movement; if paralysed on one side the unaffected side will rise further and pull the uvula towards the normal side.

ACCESSORY NERVE

The spinal part of the accessory nerve may be damaged in the posterior triangle, paralysing the upper part of trapezius (but not always the lower part—p. 427). Test by asking the patient to shrug the shoulder. A lesion higher up before the nerve enters sternocleidomastoid will paralyse that muscle also; test by turning the face to the opposite side.

HYPOGLOSSAL NERVE

Paralysis of this nerve makes its own half of the tongue immobile and if of long standing the tongue will be wasted on that side. Test by asking the patient to put out the tongue; it will deviate towards the affected side due to the unopposed action of the normal half.

8. Osteology of the skull

PART 1 INTACT SKULL

Strictly speaking, the term *skull* includes the mandible, and the *cranium* is the skull without the mandible, but *cranium* is often used to mean the part of the skull containing the brain. This *cranial cavity* has a roof or skull-cap (cranial vault) and a floor which is the base of the skull. The *facial skeleton* is the front part of the skull and includes the mandible (Figs 8.1 and 8.2). A study

of the *intact skull* is much more fruitful than undue contemplation of each separate bone. Examination of the disarticulated skull bones displays certain features not visible in the intact skull, but the chief justification for studying individual bones is to understand their manner of articulation as they combine to build up the skull.

EXTERNAL FEATURES

Superior view

The most striking feature of the convex upper surface is its asymmetry. One side is set in front of the other, and

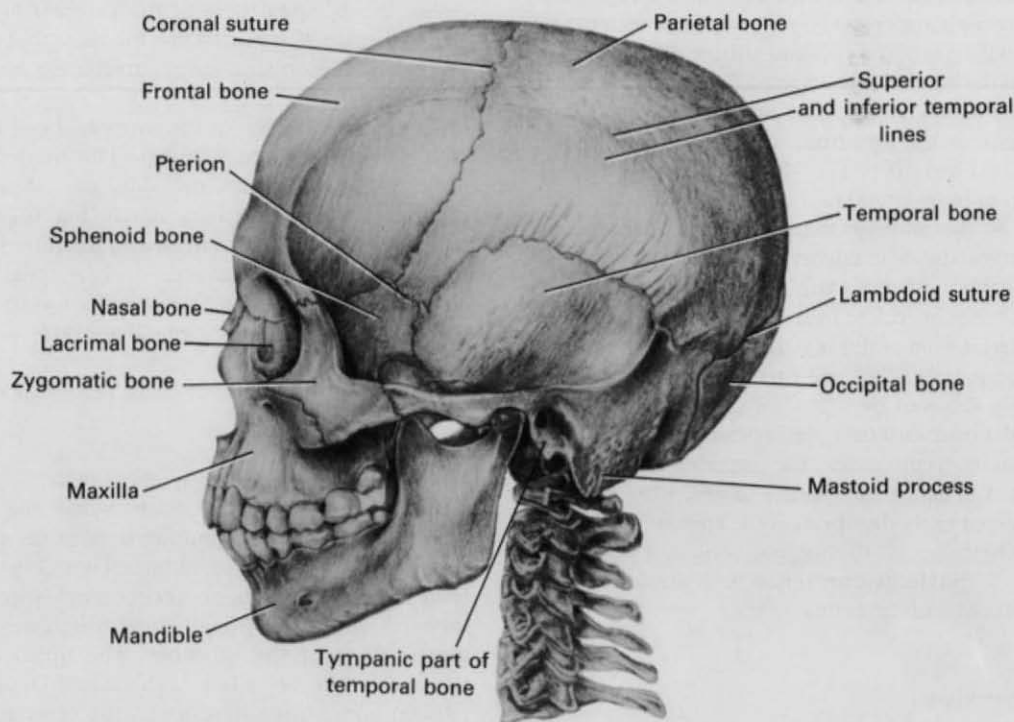


Fig. 8.1 Left side of the skull.

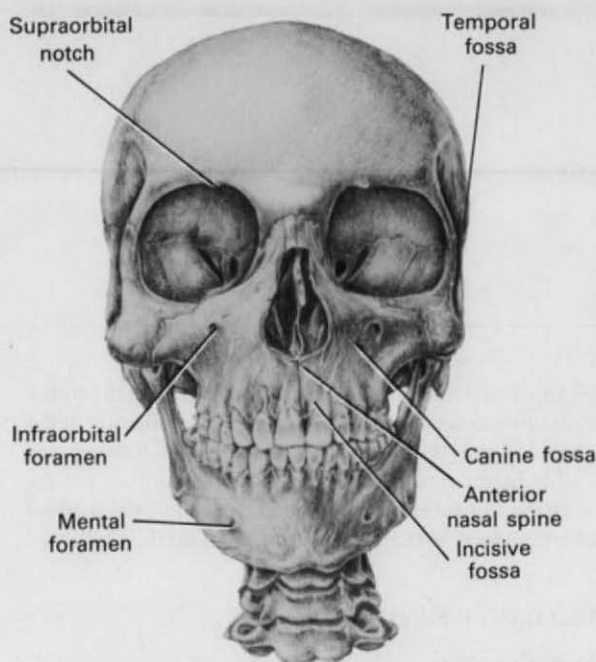


Fig. 8.2 Anterior view of the skull.

this is reflected internally by a similar asymmetry of the cerebral hemispheres and their contained lateral ventricles. Anteriorly the frontal bone articulates with the pair of parietal bones at the **coronal suture**; the original two halves of the frontal bone occasionally fail to fuse, leaving a midline *metopic suture*. The midline meeting place of the bones is the **bregma**, the site of the anterior fontanelle (Fig. 1.40, p. 47). The coronal suture is straight for 3 cm or more lateral to the bregma (this is the line of closure of the anterior fontanelle) and then becomes highly tortuous as it curves transversely down to the lateral surface of the skull. Behind the bregma the parietal bones articulate in the midline **sagittal suture**. The anterior 3 cm of this is straight (the line of closure of the anterior fontanelle) and then comes a tortuous part for 5 cm, followed by a straight part. Alongside this a **parietal foramen** often perforates each parietal bone; an emissary vein leaves the superior sagittal sinus through it. Thence the sagittal suture, tortuous again, curves down to the **lambda**, at the apex of the occipital bone. The centre of the parietal bone is a low prominence, the **parietal eminence**, and this lies on the profile of the skull from this view.

Posterior view

The lambda is the midline point where the sagittal

suture meets the tortuous *lambdoid suture* between the squamous part of the occipital and the parietal bones. It lies above the posterior pole of the skull. Along these sutures accessory or sutural (Wormian) bones are commonly found; they are sometimes seen along other borders of the parietal bone, including the pterion. They must be distinguished from the occasional *interparietal bone*, a large triangular bone at the apex of the occipital. This is not an accessory bone but exists as a separate entity when the cartilaginous and membranous parts of the occipital bone fail to fuse (p. 658).

Some 6 cm ($2\frac{1}{2}$ inches) below the lambda the occipital bone is projected into the **external occipital protuberance**, from which a low ridge crosses towards the base of the mastoid process. This is the *superior nuchal line* (Fig. 8.3); gently convex upwards it lies at the junction of neck and scalp. It is the surface marking of the internal attachment of the tentorium cerebelli, which straddles the transverse sinus at the roof of the posterior fossa. Trapezius and sternocleidomastoid are attached side by side here (trapezius at the medial one-third and sternocleidomastoid along the lateral two-thirds of the superior nuchal line). Splenius capitis is inserted into the lateral third of the line deep to sternocleidomastoid. Above this is the *highest nuchal line*, which gives origin to occipitalis and the galea aponeurotica; beneath this part of the scalp the bare bone covers the occipital pole of the cerebral hemisphere. Below the superior nuchal line the bone that covers the cerebellar hemispheres gives attachment to the neck muscles (p. 546).

The mastoid region of the temporal bone articulates with the parietal and occipital. The mastoid process projects down from the side, its deep surface channelled into the digastric notch (Fig. 6.75, p. 547). It is best studied in the lateral and inferior views. The suture between the mastoid and occipital bones is commonly perforated by a mastoid emissary foramen, carrying a vein from the sigmoid sinus to the posterior auricular vein (Fig. 8.4).

Lateral view

Note the sutures between the cranial bones. The **coronal suture** curves down along the posterior border of the frontal bone; it is tortuous above and straight below the inferior temporal line (Fig. 8.1). As it leaves the parietal bone the coronal suture curves forward where the frontal bone articulates with the greater wing of the sphenoid. The upper border of the greater wing articulates with the inferior angle of the parietal bone; this suture meets the coronal suture at the **pterion**, which is not a single point but an area with

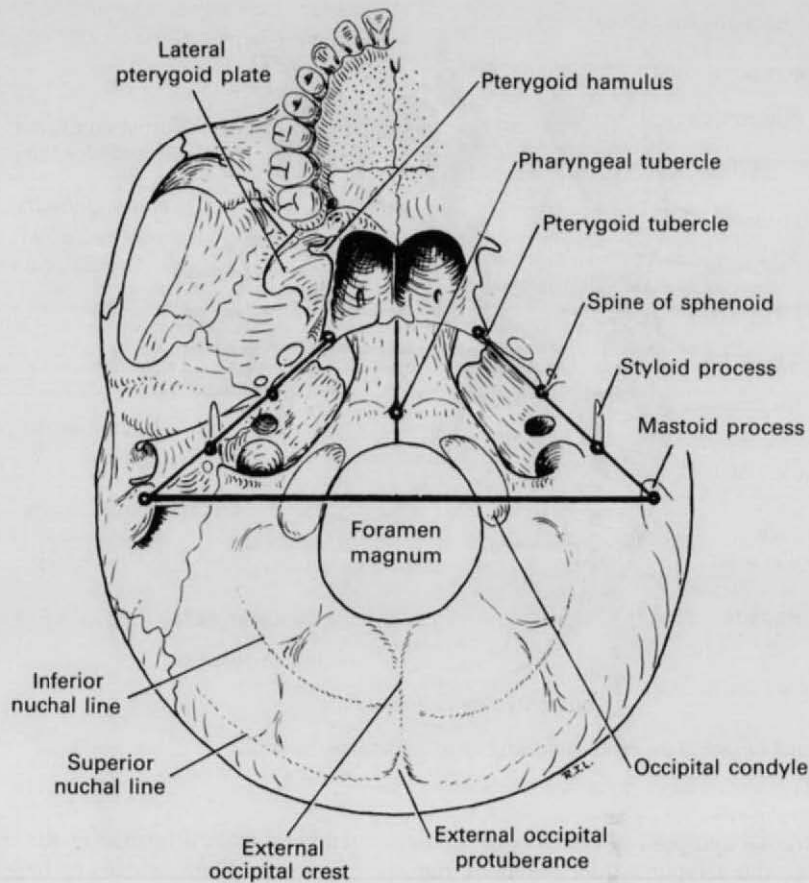


Fig. 8.3 External surface of the base of the skull, with survey landmarks.

an H-shaped pattern of sutures between frontal, parietal, temporal and sphenoid bones. The squamous part of the temporal bone articulates in front with the greater wing of the sphenoid and then arches up and back to overlap the parietal bone. The mastoid region of the temporal bone continues this suture with the parietal until posteriorly it meets the occipital bone. The meeting place of these sutures is the *asterion*.

The mastoid region of the temporal bone is projected down as the blunt **mastoid process**. To its lateral surface is attached the sternocleidomastoid, with splenius and longissimus capitis lying deep to it. The lateral surface of the mastoid process is built up by a downgrowth of bone from the squamous part of the temporal, and incomplete fusion of the two results commonly in an irregular groove, the *squamomastoid suture* just short of the borders of the mastoid process (Fig. 6.58, p. 524). In front of this is the external acoustic meatus to be studied later (p. 650). Above the meatus is a horizontal ridge, the *suprameatal crest*; this is

projected forwards as the upper border of the zygomatic process of the temporal bone. The zygomatic arch is continued by the zygomatic bone, which articulates with the maxilla and frontal bone as a pair of anterior pillars of the arch (Fig. 8.1). The arch is further described on page 454.

The frontal process of the zygomatic bone meets the frontal bone at the **frontozygomatic suture** which is palpable in the living and is used as a landmark for the pterion (above). The zygomatic bone has a sharp posterior border which continues up across the suture as a ridge on the frontal bone. This ridge arches up and back and diverges into the superior and inferior **temporal lines**. The superior line is traceable around its convexity down towards the mastoid process. The temporalis fascia is attached to the superior line and to the polished strip of bone between the two lines and sweeps down to be attached to the upper border of the zygomatic bone and arch. The inferior temporal line curves around from the zygomatic process of the frontal

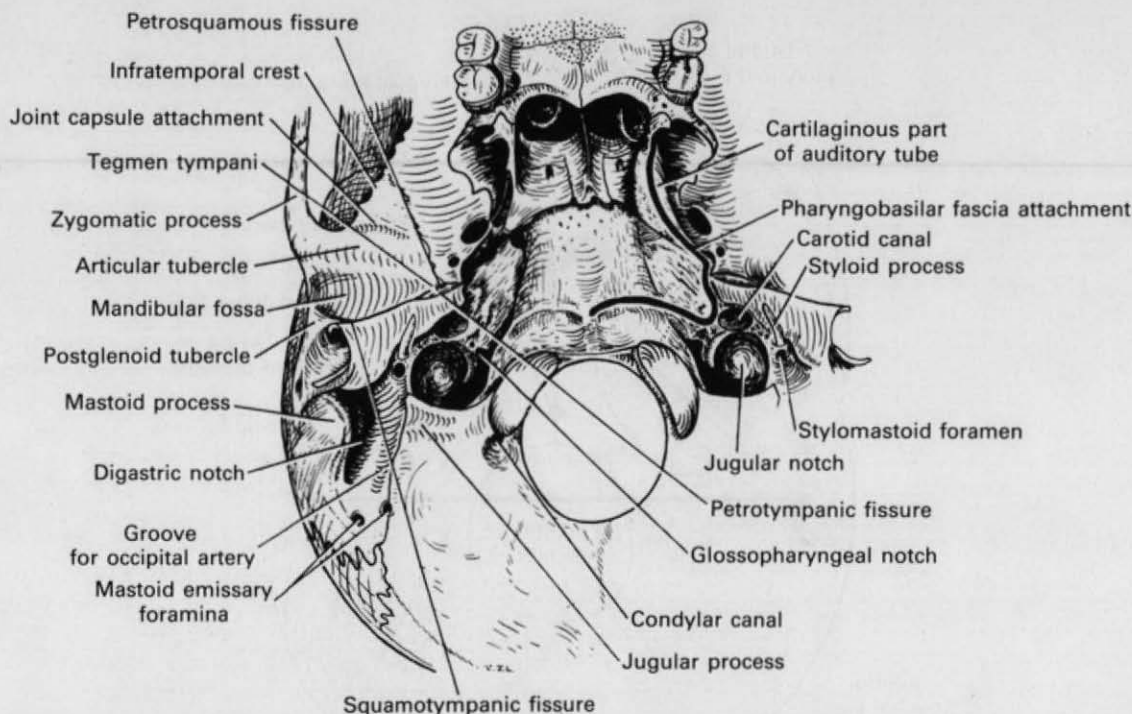


Fig. 8.4 External surface of the central and left part of the base of the skull.

bone across the frontal and parietal bones as far as the mastoid region of the temporal bone. Here it runs forward into the suprameatal crest (Fig. 8.1).

The **temporal fossa** is the area bounded by the superior temporal line, zygomatic arch and the frontal process of the zygomatic bone. In the fossa the greater wing of the sphenoid articulates behind with the squamous temporal to form a convexity which is the lateral wall of the middle cranial fossa, and it articulates in front with the zygomatic bone to form a deep concavity which is the lateral wall of the orbit. The upper border of the greater wing articulates with the parietal and frontal bones; sutural bones are commonly found here, and this is the region of the pterion. The lower limit of the temporal surface of the greater wing is marked by a line of sharp tubercles, the *infratemporal crest*; this is level with the upper border of the zygomatic arch. On the squamous bone a vertical groove lies above the external acoustic meatus. This lodges a deep vein and artery of the superficial temporal vessels. Temporalis arises from the whole surface of the temporal fossa. The posterior pillar of the zygomatic arch is grooved to lodge the posterior fibres of the muscle, which glide to and fro across it during mandibular movement. The anterior wall of the

temporal fossa is formed by the concave surface of the zygomatic bone which is here perforated by the zygomaticotemporal nerve.

The zygomatic process of the temporal bone is hollowed by the mandibular fossa in front of the external acoustic meatus; in front of this is the articular tubercle. Note the position of the mandible (Fig. 8.1). Its condyle is in the mandibular fossa and the coronoid process lies under cover of the temporozygomatic suture. Remove the mandible and reserve it for future study.

The **zygomatic arch** is formed by the zygomatic process of the temporal bone and the temporal process of the zygomatic bone; they meet at an oblique suture near the front end of the arch. (The term 'zygoma' should not be used; it can mean either the arch or the zygomatic bone.) At the front the frontal process of the zygomatic bone and the zygomatic process of the maxilla can be considered as the anterior pillars of the arch. The superficial head of masseter arises from the lower border of the arch and as far forwards as the maxilla, and the deep head arises from the concave medial surface of the arch. The temporomandibular ligament is attached to the lateral surface of the articular tubercle deep to the parotid fascia, whose

superficial layer is attached to the lower border of the arch in front of this. The temporalis fascia is attached to the upper border of the arch. The arch is crossed in front of the external acoustic meatus by the auriculotemporal nerve and the superficial temporal vessels. Further forward the arch is crossed by the upper and lower zygomatic branches of the facial nerve. The nerves are vulnerable on this subcutaneous bone, and their division will endanger vision from inability to close the lids with resulting desiccation and ulceration of the cornea. Deep to the arch the temporalis slides freely up and down with movements of the mandible.

The zygomatic bone forms the bony prominence of the cheek; it is perforated by the zygomaticofacial foramen, sometimes double, for the zygomaticofacial nerve. When no foramen is visible the zygomaticofacial nerve has perforated the surface by multiple small filaments. Zygomaticus major arises from the surface of the zygomatic bone, and zygomaticus minor from the zygomaticomaxillary suture.

Below the arch the upper jaw can be studied. The posterior convexity of the maxilla nears the lower part of the **lateral pterygoid plate**; inferiorly the *pyramidal process* (tubercle) of the palatine bone is wedged between them (Fig. 8.5). The maxilla and pterygoid plate are separated above this by the **pterygomaxillary fissure** (Fig. 6.11, p. 448). In its depths lies the *pterygopalatine fossa*, and the *sphenopalatine foramen* can be seen here, opening into the lateral wall of the nose. The fossa is not fully visible in the intact skull (it is described on p. 466).

The **tuberosity of the maxilla** is a prominent boss of bone that projects above the *posterior* surface of the last molar tooth (Fig. 8.4). The buccinator arises from a linear strip on the body of the maxilla; the line extends from level with the anterior border of the first molar tooth, skirting the base of the zygomatic process of the maxilla and keeping well above the alveolar bone until it turns down posteriorly to the tuberosity. From the tuberosity a fibrous band, the pterygomaxillary ligament (Fig. 6.11, p. 448) for the origin of the buccinator passes to the tip of the hamulus. Below the line of buccinator is the vestibule of the mouth; above it are the soft tissues of the face. From the tuberosity of the maxilla and the pyramidal process of the palatine bone the small inferior head of the medial pterygoid arises overlapping the inferior head of the lateral pterygoid, which arises from the whole surface of the lateral pterygoid plate. The posterior convexity of the maxilla above the tuberosity shows two or more foramina for the posterior superior alveolar nerves and vessels.

The zygomatic process of the maxilla forms the anterior pillar of the zygomatic arch. It is palpable

through the cheek, or better still in the vestibule (feel your own!). It is hollowed by the apex of the maxillary sinus. The anterior pillar of the zygomatic arch is buttressed higher up, for here the zygomatic bone articulates with the zygomatic process of the frontal bone.

The **piriform** (anterior nasal) **aperture**, bounded below by the sharp projection of the anterior nasal spine, is on the profile of the skull, but the face bones visible from this aspect are best studied from in front. Note in this lateral view, however, the ridge formed by the root of the canine tooth. Between the canine ridge and the zygomatic process is the *canine fossa*. Between the canine ridge and the midline is the *incisive fossa*. (Note that the term 'incisive fossa' is also used to denote the small pit on the hard palate into which the incisive foramen opens; see p. 480).

Anterior view

The **frontal bone** (sometimes bisected by a *metopic suture*) curves down to make the upper margins of the orbits (Fig. 8.2). Medially it goes down to meet the frontal process of each maxilla, between which it articulates with the nasal bones. Laterally it projects down as a zygomatic process to make the frontozygomatic suture with the zygomatic bone at the lateral margin of the orbit. Postpone the study of the orbital cavity (p. 505) and note that the frontal bone occupies the upper third of the anterior view of the skull, the maxillae and mandible making the other two thirds.

The nasal bones curve downwards and forwards from their articulation with the frontal bone. Each articulates with the frontal process of the maxilla, and they arch forward to meet in a midline suture. The lower border of each is notched by the external nasal nerve. These free borders make with the two maxillae a pear-shaped piriform (anterior nasal) aperture (Fig. 8.2). In the nasal cavity the bony septum and the conchae of the lateral wall are visible, but their study is best postponed. The two maxillae meet in a midline intermaxillary suture, and are projected forward as the **anterior nasal spine** at the lower margin of the nasal aperture. The canine root makes a ridge on the anterior surface of the maxilla. Between this and the intermaxillary suture lies a slight depression unofficially called the incisive fossa (but this is confusing since that is the proper name for the space into which the incisive canals open at the front of the hard palate — p. 479). The incisive slips of orbicularis oris arise high in this fossa, near the midline. Lateral to the canine ridge is the **canine fossa**, from which levator anguli oris arises. Above this the anterior surface of the maxilla is perforated by the infraorbital foramen. Levator labii superi-

oris alaeque nasi arises from the frontal process of the maxilla, and levator labii superioris arises from the lower margin of the orbit (i.e. from maxilla and zygomatic bone) and hangs down like a curtain over the infraorbital foramen and its issuing nerve. Note that the attachments of buccinator and levator anguli oris, horizontal around the body of the maxilla, bisect the maxillary sinus, which lies with its lower half deep to the vestibule and its upper half deep to the soft tissues of the face. Nearer the midline the incisive slips of orbicularis oris arise from the same horizontal level; the mucous membrane of the vestibule is reflected from the maxilla to line all these muscles. As before, the study of the mandible will be deferred, but while it is in position note that the supraorbital notch, infraorbital foramen and mental foramen lie all three in a vertical line. The osteology of the orbital walls and margin is summarized on page 505.

Inferior view

Discard the mandible and look at the inferior surface of the skull, otherwise known as the external surface of the base. The occipital, temporal and part of the sphenoid bones makes the base of the cranium behind the face bones (Fig. 8.3).

The area behind the foramen magnum is simple, and consists largely of the squamous part of the occipital bone. From the mastoid process to the external occipital protuberance the **superior nuchal line** lies in a curve concentric with the foramen magnum. Halfway between them the **inferior nuchal line** is concentric with both. The **external occipital crest**, in the midline between the external occipital protuberance and the foramen magnum, bisects this area. A rather vague line, radiating back and outwards from the foramen magnum, further bisects each half. Thus four areas are demarcated in each half (Fig. 8.3). There are two alongside the foramen magnum and they receive the rectus muscles: the medial area receives rectus capitis posterior minor and the lateral area receives rectus capitis posterior major (Fig. 6.75, p. 547). Between superior and inferior nuchal lines the medial area receives semispinalis capitis and the lateral area gives attachment to the superior oblique muscle of the head.

The area in front of the foramen magnum is more difficult. It is a complicated mixture of processes and foramina, but do not be dismayed. A general survey will clarify the picture, and the following 'one-third:two-thirds' summary will prove useful (Fig. 8.3).

General survey. Join the tips of the mastoid processes. One-third of the **foramen magnum** lies in

front and two-thirds behind this line. The occipital condyles have the reverse proportions; two-thirds of the condyle lies in front of the line. Now identify the pterygoid tubercle by tracing the posterior border of the medial pterygoid plate from the hamulus up to the base of the skull. Here the pterygoid tubercle projects back towards the foramen lacerum. Note that the back of the nose (between the medial pterygoid plates) is the *same width as the diameter of the foramen magnum*, and is set forward at such a distance that a line joining the tip of the mastoid process to the pterygoid tubercle slants in at 45° — right and left lines lie at right angles to each other. This 45° slant along the petrous part of the temporal bone imprints itself on many structures at the base of the skull. *The line is divided into thirds* by the *styloid process* and *spine of the sphenoid*, so the stylomastoid foramen and the foramen spinosum can be located. The stylomastoid foramen lies behind the base of the styloid process, and the foramen spinosum perforates the base of the spine of the sphenoid. The spine of the sphenoid overlies the opening in the petrous bone of the bony part of the auditory tube. The cartilaginous part of the tube, slanting at 45° , lies below the slit between the greater wing of the sphenoid and the apex of the petrous bone (Fig. 8.4). The foramen ovale perforates the greater wing along a 45° slant anterior and medial to the foramen spinosum. Lateral to the pterygoid tubercle is the scaphoid fossa; from here to the spine of the sphenoid tensor palati arises from the greater wing along the 45° slant.

One-third of the way from the anterior margin of the foramen magnum to the back of the nasal septum (vomer) the **pharyngeal tubercle** projects from the basiocciput (Fig. 8.3). On either side a ridge curves laterally, marking the attachment of the prevertebral fascia and the pharyngobasilar fascia. The attachment of the pharynx can now be marked out on the base of the skull (p. 487). Note that the apex of the petrous bone with its attached levator palati muscle lies wholly in the pharynx (Fig. 8.4).

From this general survey attention can now be given to further details on individual skull bones.

Occipital bone. This has a basilar part, commonly called the basiocciput, in front of the foramen magnum, a lateral part on each side bearing condyles, and a squamous part behind and above the foramen. The **foramen magnum** is oval in shape, its long diameter being anteroposterior. Its transverse diameter is rather less than one third of the distance between the mastoid processes (Fig. 8.3). The fibrous dura mater is attached to the margins of the foramen as it sweeps down from the posterior cranial fossa. Within the tube of dura mater the lower medulla with the spinal arteries and

veins, the vertebral arteries and the spinal roots of the accessory nerves traverse the foramen in the subarachnoid space (Fig. 6.96, p. 573). Meningeal branches of the vertebral artery and communicating veins from the occipital sinuses to the internal vertebral plexus lie outside the fibrous dura, between it and the periosteum of the foramen magnum laterally and posteriorly. Anteriorly the margin of the foramen gives attachment to the ligaments sweeping up from the axis. Adherent to dura mater is the tectorial membrane and in front of this is the vertical limb of the cruciform ligament; in front again are the apical and the pair of alar ligaments of the dens of the axis. All are attached, in front of the dura mater, to the anterior margin of the foramen magnum. The alar ligaments are attached each to a triangular area medial to the anterior pole of the occipital condyle. These triangular areas are limited anteriorly by a ridge that joins the anterior poles of the occipital condyles. The anterior atlanto-occipital membrane is attached to the ridge. The posterior atlanto-occipital membrane is attached to the posterior margin of the foramen magnum; observe that this is a curve of more than half the foramen. Both membranes are attached right up to the capsules of the atlanto-occipital joints. Tangential with the posterior margin of the foramen magnum is the line of fusion between the squamous and jugular parts of the occipital bone (it fuses at the second year, see p. 658).

The **occipital condyles** are convex kidney-shaped surfaces, covered with hyaline cartilage, beside the front half of the foramen magnum. Their posterior poles are separated by the diameter of the foramen, but their anterior poles are much closer together. The two convexities make a ball-and-socket joint with the atlas. But the anteroposterior curve is more pronounced than the combined side to side curvature; the ball is oval-shaped, like an egg lying on its side, and thus permits nodding and some abduction but *no rotation*. The capsule and synovial membrane are attached to the articular margins. The epiphyseal cartilage between basiocciput and exocciput crosses this joint. Fusion (at the sixth year) is sometimes incomplete and the condyle may then possess two separate articular surfaces. Behind the condyle is the shallow *condylar fossa* floored by thin bone. This is commonly perforated by the *condylar canal*, carrying a vein from the bottom of the sigmoid sinus to the suboccipital venous plexus. Deep to the summit of the occipital condyle at the site of the original epiphysis the bone is perforated by the *hypoglossal canal*. The hypoglossal nerve enters this as two roots, separated by a flange of fibrous dura mater. The flange may ossify but does not extend to the anterior aperture of the canal, for here the nerve issues

as a single trunk, medial to the jugular foramen. This foramen, lateral to the canal, is bounded by the jugular notch in the lateral projection of the occipital bone called the **jugular process** (Fig. 8.4). The jugular process articulates laterally with the mastoid part of the temporal bone; the occipital artery grooves the suture between them. The jugular process, at the posterior margin of the jugular foramen, gives attachment to rectus capitis lateralis, and the prevertebral fascia is attached to the edge of the bone behind the internal jugular vein (Fig. 6.6, p. 441).

The **basiocciput** extends forward from the foramen magnum and fuses (at 25 years) with the basisphenoid just behind the nose and 2.5 cm (1 inch) in front of the foramen magnum. In front of the pharyngeal tubercle the bone forms the roof of the nasopharynx, whose mucous membrane is attached to the periosteum. Alongside the pharyngeal tubercle the ridges, convex forwards, for the prevertebral fascia and pharyngobasilar fascia have already been noted (Fig. 8.4). Behind each is the insertion of longus capitis, with rectus capitis anterior behind this muscle, immediately in front of the occipital condyle and medial to the hypoglossal canal (Fig. 6.6, p. 441).

The *squamous* part of the occipital bone has already been studied (pp. 644 and 648).

Temporal bone. There are four parts of this bone, separately ossified and afterwards fused. The petrous part (often called petromastoid to indicate that the mastoid region belongs mostly to the petrous part), set at a slant of 45°, forms a substantial part of the skull base alongside the occipital bone. The *squamous* part, undulating from the concavity of the mandibular fossa to the convexity of the articular tubercle, makes a small part of the skull base lateral to this, but most of the squamous part is in the temporal fossa on the side wall of the skull. The zygomatic process belongs to the squamous parts. There is an anterior angle between the squamous and petrous parts, and here the greater wing of the sphenoid is slotted in. The *tympanic* part, rolled up like a scroll, lies below the petrous and squamous parts, and behind it the *styloid process* projects like a carpenter's nail from the surface of the petrous bone. Study these four parts of the temporal bone in turn (Fig. 8.4).

The **mastoid process** is grooved, sometimes deeply, by the digastric notch for the origin of the posterior belly of the digastric. Medial to this notch a groove for the occipital artery indents the bone along the temporo-occipital suture. The base of the **styloid process** lies one-third of the way from the tip of the mastoid process to the pterygoid tubercle. The length of the process is very variable. The stylopharyngeus arises high up

medially, the stylohyoid high up posteriorly, and the styloglossus low down in front. The stylohyoid ligament passes on from its tip. Behind its base is the stylomastoid foramen, transmitting the facial nerve and the stylomastoid branch of the posterior auricular artery. Medial to the styloid process the petrous bone is deeply hollowed out to form the jugular notch. The shallower jugular notch in the occipital bone lies behind, and the two notches form the jugular foramen, which here lodges the jugular bulb at the beginning of the internal jugular vein. Anteromedially each bone has a smaller notch for the anterior part of the jugular foramen. Here emerge the vagus and accessory nerves with, in front of them, the glossopharyngeal nerve and the inferior petrosal sinus. The glossopharyngeal itself makes a deep notch in the petrous bone (better seen from the posterior cranial fossa) and here lie its sensory ganglia. In the floor of the notch is the external opening of the cochlear canaliculus (aqueduct of the cochlea).

Anterior to the jugular notch the **petrous part** is perforated by the **carotid canal**. The internal carotid artery enters here and turns forward into the bone. The carotid sheath is attached to the margins of the canal. The ridge of the bone between the jugular notch and the carotid canal is perforated by multiple small foramina. One of these in the centre of the ridge transmits the tympanic branch of the glossopharyngeal nerve; the others carry caroticotympanic branches from the internal carotid artery and sympathetic filaments from the carotid plexus. Anterolateral to the carotid canal, at the margin of the petrous bone, is the opening of the *bony part of the auditory tube*, overlapped somewhat by the spine of the sphenoid. Introduce a bristle into the opening and note that it passes back into the middle ear. Lay the other end of the bristle over the third molar tooth of the opposite side; the first 2.5 cm of the bristle as it emerges from the bony tube indicates the exact line and inclination of the cartilaginous part of the tube. Note that the tube is not parallel with the base of the skull but passes downwards towards its nasopharyngeal opening at an angle of about 20°. The apex of the petrous bone, rectangular from this view, passes forward at 45° to lodge itself between the basiocciput and greater wing of the sphenoid. No sutures are formed here, and a wide slit often lies between the petrous bone and the greater wing. The cartilaginous part of the auditory tube is lodged below the slit, on a 45° anteromedial slant. Levator palati arises from the rectangular area at the apex of the petrous and from the cartilaginous tube. The pharyngobasilar fascia is attached behind levator palati, anterior to the carotid canal, and the mucous membrane of the nasopharynx is attached in front of the muscle. The extreme tip of the

petrous bone, perforated by the internal carotid artery as it turns up into the middle cranial fossa, varies greatly in shape. This irregularity forms a boundary of the *foramen lacerum* between the basiocciput and the greater wing of the sphenoid. The foramen lacerum is completely closed here in life by dense fibrous tissue that extends across from the periosteum of the adjacent bones. Apart from minute emissary veins no major structure passes through the foramen lacerum from the cranial cavity to the exterior.

The **tympanic part** (Fig. 8.1) is a scroll-like piece of bone projected into a sharp lower border which lies in the characteristic 45° anteromedial obliquity. The part of it that is indented forwards by the styloid process (Fig. 8.4) is the vaginal process. The deep layer of the parotid fascia is attached to the sharp border as far medially as the carotid canal. The parotid fascia is thickened between the vaginal process and angle of the mandible as the *stylomandibular ligament*. (The thickening might unambiguously have been called the *vaginomandibular ligament*.)

The tympanic part is C-shaped in section, open above. Laterally it is lodged below the squamous and mastoid parts, and here forms the bony part of the **external acoustic meatus**. More medially it lies below an excavation in the petrous part and here forms the bony wall of the middle ear. Now make the postponed inspection of the lateral margin of the tympanic part. The bone is everted somewhat, and to its margins is attached the cartilaginous part of the external acoustic meatus. Posteriorly the bone lies against the mastoid process, and the trespassing auricular branch of the vagus emerges from its imprisonment between the two bones. Anteriorly the tympanic part rests against a flange of squamous bone unofficially but appropriately named the postglenoid tubercle (Fig. 8.5). Note now that the squamous bone carries a sharp crest, the *suprameatal spine*, in the gap between the margins of the tympanic part; it completes the bony ring of the external acoustic meatus. A horizontal upper tangent and a vertical posterior tangent of the meatus enclose with the suprameatal spine a concavity clinically named the *suprameatal triangle*. This is the mark for the tympanic antrum, which lies 15 mm deep to the surface. Through the depths of the meatus can be seen the promontory of the middle ear, sometimes etched by fine lines made by the tympanic plexus. The round and oval windows can be seen too, for there is no tympanic membrane to obstruct this view of the medial wall of the middle ear.

Return now to the inferior view of the skull base. The tympanic and squamous parts meet at the transverse *squamotympanic fissure* in the mandibular fossa

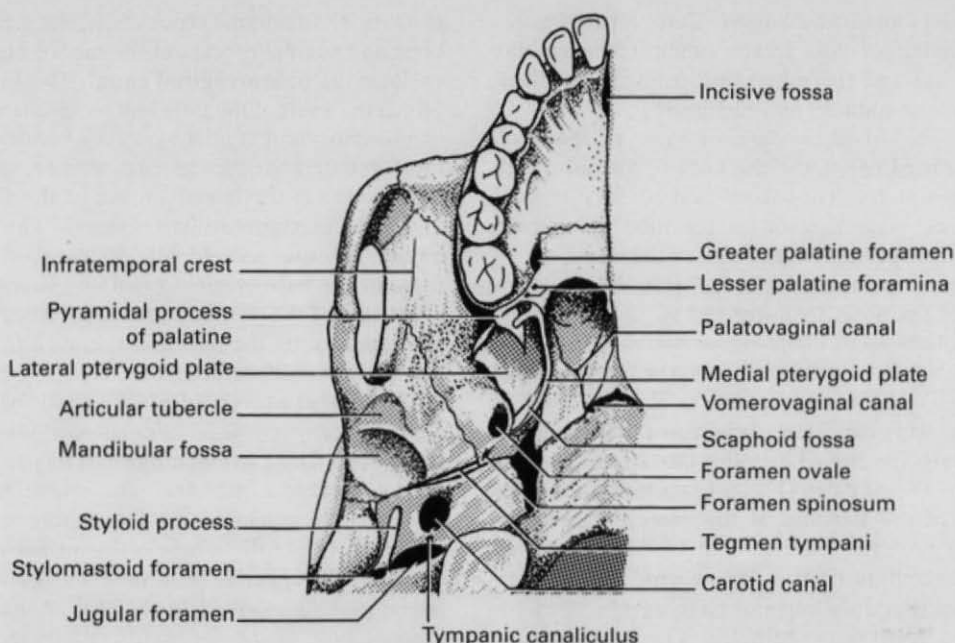


Fig. 8.5 Left infratemporal and palatal regions of the base of the skull.

(Fig. 8.4). Here is attached the capsule of the mandibular joint. In the depths of this fissure, well to the medial end, behind the spine of the sphenoid, is a thin flange of bone. This is the projecting margin of the *tegmen tympani*, part of the petrous bone that has grown down from the roof of the middle ear (p. 48). It divides the medial end of the squamotympanic fissure into the *petrosquamous fissure* in front, for the capsule of the jaw joint, and the *petrotympanic fissure* behind. Deep in the petrotympanic fissure the chorda tympani emerges and passes down in a groove on the medial surface of the spine of the sphenoid. Inspect once again the opening of the bony part of the auditory tube and note that the flange from the tegmen tympani forms its lateral boundary. The flange encloses, in fact, the canal for the tensor tympani muscle (Fig. 8.8).

The **squamous part** of the temporal bone (most of which is seen on the lateral side of the skull) is hollowed out to form the **mandibular fossa**. This rather spoon-shaped concavity does not lie completely transversely but slightly obliquely, with its lateral end a little farther forward than the medial end; this is to conform with the obliquity of the condyle of the mandible (p. 665). The capsule of the joint is attached to the medial and lateral margins of the fossa. In front of the fossa is the convexity of the *articular tubercle*. The lateral extremity of this transverse ridge projects at the lower margin of the zygomatic process. Anterior to the convexity of the

tubercle is a curved line which marks the attachment of the capsule of the temporomandibular joint (Fig. 8.5). A small triangular area of squamous bone in front of this forms part of the infratemporal surface of the skull. From the region of the fossa and tubercle the zygomatic process projects laterally, then forwards; it belongs to the squamous part of the bone.

Sphenoid bone. Only the greater wing enters into the base of the cranium here. It forms a suture with the squamous temporal. Together these make the infratemporal surface, the size of a thumb print, and the pad of the thumb rests comfortably here. The upper head of lateral pterygoid arises from this surface. Anteriorly the surface ends at the inferior orbital fissure behind the maxilla. Medially the greater wing ends in a straight edge alongside the 45° obliquity of the apex of the petrous bone. The posterior end of this edge projects down as the *spine of the sphenoid*, whose base is perforated by the *foramen spinosum* for the middle meningeal vessels (Fig. 8.5). The sphenomandibular ligament is attached to the tip of the spine. Forwards and medially is the much larger *foramen ovale* for the mandibular nerve. Medial to the foramen ovale may be a small *venous foramen* (of Vesalius) for a vein joining the cavernous sinus to the pterygoid plexus. Behind the foramen ovale, less commonly, may be the small *petrosal foramen* for the lesser petrosal nerve. When these foramina do not exist the vein and the nerve

traverse the foramen ovale itself. Tensor palati arises from the edge of the greater wing (between the scaphoid fossa and the spine) and from the cartilaginous part of the auditory tube alongside it.

Towards the front the inferior view of the skull exposes the hard palate and the back of the nose, with the pterygoid plates. The medial and lateral pterygoid plates project down from a common **pterygoid process** of the sphenoid at the base of the skull.

The **medial pterygoid plate** forms the posterior boundary of the nose. Its lower end is projected laterally as a delicate spur, the *pterygoid hamulus* (Fig. 8.3). To its tip is attached a fibrous band (the pterygomaxillary ligament) which passes across to the tuberosity of the maxilla. This band gives origin to the buccinator, and it converts the curved hamulus into a fibro-osseous canal for the tensor palati (Fig. 6.11, p. 448). Attached to the tip of the hamulus is the pterygomandibular raphe. The posterior border of the medial pterygoid plate is projected into a spur, below which the pharyngobasilar fascia and the superior pharyngeal constrictor are attached down to the hamulus. The expanded free end of the cartilaginous tube is slotted against the border of the medial pterygoid plate above the spur. The upper end of the medial plate projects back into the foramen lacerum as the pterygoid tubercle already seen (Fig. 8.5). From the spur a slender ridge runs up to the base of the skull towards the lateral pterygoid plate; the deeply concave **scaphoid fossa** is thus enclosed lateral to the pterygoid tubercle. From the fossa the anterior fibres of tensor palati arise. The pterygoid tubercle projects beyond the opening of the **pterygoid canal** in the foramen lacerum. A bristle inserted here will traverse the canal and enter the pterygopalatine fossa. This access from below is closed in life by a dense fibrous tissue that floors the foramen lacerum, but in the dried skull it is easier to enter the canal from below. In some skulls the opening of the canal is actually visible from below (see p. 656). A glance at a disarticulated sphenoid bone will clarify this point (Fig. 8.7); the posterior opening of the pterygoid canal is in the same vertical line as the medial pterygoid plate.

In the roof of the nose the medial pterygoid plate extends medially below the body of the sphenoid to articulate with the vomer. This medial extension of the roof of the medial pterygoid plate, ensheathing the body of the sphenoid, is the **vaginal process**. A vomerovaginal suture is thus formed, opening posteriorly as the *vomerovaginal canal*. Through it passes the minute pharyngeal branch of the sphenopalatine artery. In the lateral wall of the nose the vertical plate of the palatine bone articulates with the medial pterygoid

plate (p. 473), and the articulation between the palatine bone and vaginal process of the medial pterygoid plate encloses the **palatovaginal canal**. This opens posteriorly in the vault of the nose half a centimetre in front of its posterior limit (Fig. 8.5). Pass a bristle through this canal; it enters the pterygopalatine fossa, as can be seen by a glance at the lateral surface of the skull, looking into the pterygomaxillary fissure. The pharyngeal branch of the pterygopalatine ganglion runs back through the palatovaginal canal and supplies the back of the roof of the nose and thence the nasopharynx. It is accompanied by the pharyngeal branch from the third part of the maxillary artery.

The **lateral pterygoid plate** extends back and laterally into the space of the infratemporal fossa (Fig. 8.5). It is a bony flange whose purpose is to give attachments to the pterygoid muscles. The whole of its lateral surface gives origin to the lower head of the lateral pterygoid, while the whole of its medial surface gives origin to the upper head of the medial pterygoid. The lateral plate is attached to the base of the skull at the anterior pole of the foramen ovale; it springs from a common stem with the medial plate.

The adjacent lower borders of the two plates are excavated into the triangular *pterygoid notch* (Fig. 8.7). This is filled by the triangular extremity of the pyramidal process of the palatine bone (Fig. 8.11).

The **hard palate** (p. 480) is arched more by the downward projecting alveolar processes of the maxillae than by any upward concavity of the palatal processes. The incisive foramina and fossa and the greater and lesser palatine foramina have already been studied (pp. 480 and 466). The sharp crest of the palatine bone forms the posterior border of the greater palatine notch, which fits a similar notch in the body of the maxilla to make the *greater palatine foramen*. The crest curves back towards the midline, where it becomes less prominent and fades out in the backward projection of the bone at the midline *posterior nasal spine*. Behind the crest the palatine bone is perforated by two or three lesser palatine foramina. Here the palatine bone forms its *pyramidal process* (formerly called the tubercle of the palatine) which projects laterally behind the tuberosity of the maxilla and then expands to occupy the notch between the lower borders of the pterygoid plates of the sphenoid (Fig. 8.12).

The *teeth* (p. 477) are carried in the alveolar process of the maxilla, which projects behind the palatal process to articulate with the horizontal plate of the palatine bone (Fig. 8.5). Two incisors, one canine, two premolars (bicuspid) and three molars make up the permanent teeth of each maxilla, matching those in each half of the mandible (see p. 663).

INTERNAL FEATURES

The osteology of the nasal septum and lateral wall of the nose has been dealt with on page 473. Study these in a split skull.

The skull sutures are much less tortuous inside than outside and they ossify sooner; each suture ossifies slowly from within out, and this process begins at about 40 years.

The inner surface of the **cranial vault** shows a midline groove, widening as it is traced back, for the superior sagittal sinus. Pits in and lateral to the groove are the indentations of arachnoid granulations, those outside the sinus being in the lateral blood lakes. The grooves for the anterior and posterior branches of the middle meningeal vessels run back and up across the side of the skull and reach the vault. Their surface markings can now be checked (p. 562).

The internal surface of the **base of the skull** is in three levels, like the steps of a staircase: the anterior, middle and posterior **cranial fossae**. The anterior fossa lodges the frontal lobe and its floor is level with the upper margin of the orbit. The middle fossa lodges the temporal lobe and its floor is level with the upper border of the zygomatic arch. The posterior fossa lodges the brainstem and cerebellum and the attachment of its roof (the tentorium) lies behind the suprameatal crest along the superior nuchal line, at the upper limit of the neck muscles.

The **anterior cranial fossa** lies highest of the three. Its posterior boundary is a sharp concavity made by the lesser wing of the sphenoid (Fig. 6.89, p. 561). Laterally the lesser wing meets the frontal bone and greater wing, and so the posterior border is continued to the side wall of the skull at the pterion. Here the bone is commonly tunnelled for a short distance by the anterior branch of the middle meningeal artery running up and back. The medial end of the lesser wing is projected back as the anterior clinoid process. In front of this the base of the lesser wing is perforated by the *optic canal*, but this is in the middle cranial fossa, as is the prechiasmatic groove between the two canals; the anterior margin of the groove is the dividing line centrally between the anterior and middle fossae. The bone in front of the groove is the jugum of the sphenoid, the 'yoke' joining the two lesser wings together. The jugum (part of the body of the sphenoid) articulates in front with the cribriform plate of the ethmoid. (In many Asiatic skulls the two halves of the frontal bone fuse in the midline between the cribriform plate and the body of the sphenoid).

The orbital part of the frontal bone is the largest contributor to the anterior fossa. Over the orbit it is convex and ridged in roughly H-shape in conformity

with the orbital surface of the frontal lobe of the cerebral hemisphere. The frontal sinus invades a variable area at the anteromedial part of the roof of the orbit. Medially the upward convexity is replaced by a flatter part which roofs in the ethmoidal sinuses and articulates with the cribriform plate. Anteriorly the groove for the sagittal sinus is traceable down as a midline crest for the falx cerebri, and behind the lower end of the crest is the foramen caecum, which is plugged by the fibrous tissue of the falx, making a huge Sharpey's fibre. The midline of the cribriform plate is projected up as a sharp triangle, the crista galli, for attachment of the falx. Alongside the anterior end of the crista galli is an elongated slit. Pass a bristle through the anterior ethmoidal foramen in the medial wall of the orbit; it will pass obliquely forwards between frontal and ethmoid bones and lie over the cribriform plate. This is the oblique course of the anterior ethmoidal nerve and vessels (Fig. 6.89, p. 561), which, beneath the fibrous dura mater, lie on the cribriform plate and enter the roof of the nose through this slit, which has no official name but which might be called the nasal slit. The remaining perforations, small and round, in the cribriform plate are for the olfactory nerves. At the posterolateral angle of the cribriform plate a shallow fossa indents the frontal bone; this lodges the olfactory bulb.

The **middle cranial fossa** is butterfly-shaped. The small 'body' of the butterfly is the body of the sphenoid between the clinoid processes, while the 'wings' of the butterfly expand hugely into a concavity that extends out to the lateral wall of the skull and back to the upper border of the petrous bone. The body of the sphenoid is centrally hollowed out into the **pituitary fossa**, properly called the *sella turcica* ('Turkish saddle') with a hump in front, the *tuberculum sellae* (Fig. 6.91, p. 564). At the back the transverse *dorsum sellae* ('back of the saddle') projects up, and the upper border of the dorsum sellae ends at each side as the *posterior clinoid process* (a bedpost on the back of the saddle; the anterior clinoids belong to the lesser wing of sphenoid – see above).

A sheet of fibrous dura mater, the *diaphragma sellae*, sweeps across from the tuberculum sellae to the anterior and posterior clinoid processes to roof the pituitary fossa and the cavernous sinuses. It is perforated centrally for the pituitary stalk, and the roof of each cavernous sinus is pierced anteriorly by the internal carotid artery, which grooves the medial edge of the anterior clinoid process. Medial to the carotid groove is an elevation, the *middle clinoid process*. It lies at the lateral end of the tuberculum sellae. To it and to the posterior clinoid process is attached a flange of dura mater that descends vertically between the cavernous sinus and the pituitary fossa, and sweeps medially to

floor the fossa. The tip of the anterior clinoid process gives attachment to a ridge of dura mater along the lateral border of the roof of the cavernous sinus; the ridge of dura passes lateral to the posterior clinoid process and is continued posteriorly as the free edge of the tentorium cerebelli (Fig. 6.89, p. 561).

In front of the tuberculum sellae and carotid grooves the fibrous dura mater floors the prechiasmatic groove and is projected into the optic canals around the optic nerves as they pass into the orbits. The optic chiasma lies at a higher level well behind the groove. Vertically above the groove is a space in which lies the anterior communicating artery and above that is the rostrum of the corpus callosum; this space is the chiasmatic cistern.

The side of the body of the sphenoid is grooved by the S-shaped internal carotid artery from the foramen lacerum to the anterior clinoid process, so forming the **carotid groove** (Fig. 6.91, p. 564). Lateral to this the floor of the middle fossa is made by the greater wing of the sphenoid and the temporal bone. The greater wing here borders on the apex of the petrous bone and the side of the body of the sphenoid bone, enclosing the irregular foramen lacerum. The internal carotid artery emerges from the apex of the petrous bone to occupy the upper part of the foramen lacerum and then deeply grooves the sphenoid. The lateral ridge of the groove in the sphenoid is often prominent as the *lingula* (Fig. 6.91, p. 564). Beneath the lingula is the *opening of the pterygoid canal*, but it is more difficult to introduce a bristle into the foramen under the lingula than from the base of the dried skull beneath the pterygoid tubercle (p. 652). This is, however, the course of the greater petrosal nerve, for the foramen lacerum is floored in by dense fibrous tissue. The nerve passes below the trigeminal ganglion and the internal carotid artery, above the fibrous floor of the foramen lacerum, to join the deep petrosal nerve at the pterygoid canal. Lateral to the foramen lacerum the apex of the petrous bone shows the trigeminal impression, occupied by the trigeminal ganglion (Fig. 6.89, p. 561).

At the tip of the apex of the petrous bone is a sharp spike, medial to which is a narrow groove for the inferior petrosal sinus and the abducent nerve. To this spike is attached the petroclinoid ligament; it extends from the spike to halfway up the side of the dorsum sellae (Fig. 6.94, p. 566). Lateral to the spike is a broad shallow groove made by the sensory root of the trigeminal nerve (the small motor root is deep to it). The trigeminal groove passes forward into the impression for the trigeminal ganglion. Lateral to this the posterior border of the middle fossa is grooved by the superior petrosal sinus, and to the lips of this narrow groove the tentorium cerebelli is attached, straddling the sinus.

The posterior border of the middle fossa is the upper border of the petrous bone. At its junction with the side wall of the skull it is grooved by the inferior temporal gyrus (Fig. 6.94, p. 566). Medial to the groove is a prominence, the *arcuate eminence*, which is made by the underlying anterior semicircular canal. Medial to the arcuate eminence the petrous bone passes forwards and medially at 45°. Its upper surface is perforated and grooved by the greater petrosal nerve; the groove passes obliquely into the foramen lacerum, and the nerve lies beneath the trigeminal ganglion here. Parallel and anterolateral to this is a small groove made by the lesser petrosal nerve; this groove is directed towards the foramen ovale.

In front of the petrous part of the temporal bone is the greater wing of the sphenoid and a small part of the squamous temporal; this area has already been seen from below as the thumb-print sized roof of the infratemporal fossa (p. 651). The greater wing is perforated by the small foramen spinosum and, anteromedial to this, by the much larger foramen ovale. From the foramen spinosum a groove for the middle meningeal artery leads forward; this soon splits into anterior and posterior branches whose courses are marked by the grooves already noted. The grooves are made by the middle meningeal veins (the so-called 'veins' are actually sinuses in the dura mater).

The *foramen ovale* perforates the greater wing in front of the trigeminal impression at the apex of the petrous temporal bone. The foramen ovale transmits the mandibular nerve, whose sensory and motor roots join in the foramen. A vein from the cavernous sinus passes down to the pterygoid plexus and the lesser petrosal nerve lies here too. The accessory meningeal artery runs up to supply the trigeminal ganglion, and the meningeal branch of the mandibular nerve (nervus spinosus) commonly runs with the artery instead of going through the foramen spinosum. Just medial to the foramen ovale the fibrous dura mater peels away from the 'endosteal layer' to stretch up as the lateral wall of the cavernous sinus. In front of the foramen ovale is the *foramen rotundum*, which opens forwards into the pterygopalatine fossa. It transmits the maxillary nerve. The fibrous dura mater of the lateral wall of the cavernous sinus blends with the periosteum of the greater wing at the lateral margin of the foramen rotundum.

The greater wing with its deeply concave forward projection into the lateral wall of the orbit fails to meet the lesser wing; the slit between them is the superior orbital fissure. Lateral to the line of the foramen rotundum this is closed by fibrous dura mater. Medial to the line of the foramen rotundum the medial end of the superior orbital fissure is open for the anterior end of the cavernous sinus and the nerves that run along it

into the orbit (p. 564). Further laterally the greater wing, very thin, makes the lateral wall of the middle fossa, which is the floor of the temporal fossa on the side of the cranium, behind the orbit. Behind this the lateral wall of the middle cranial fossa is made by the squamous part of the temporal bone. At its junction with the floor (petrous bone) it is perforated by the meningeal branch of the mandibular nerve (*nervus spinosus*) on its way to the mastoid antrum and air cells.

The anterior end of the middle fossa is roofed by the projecting lesser wing of the sphenoid. From the pterion the sphenoparietal sinus runs below the margin of the lesser wing (i.e. in the roof of the middle fossa) to the anterior clinoid process, where it enters the roof of the cavernous sinus.

The **posterior cranial fossa**, deeply concave, lies above the foramen magnum. Anteriorly, its upper limit is the upper border of the petrous temporal bone. Behind this at the same horizontal level is a wide groove on the inner surface of the skull which extends to the midline; it is made by the *transverse sinus*. The two grooves meet at the *internal occipital protuberance*, which lies opposite the external occipital protuberance. Above the internal occipital protuberance (i.e. above the posterior fossa) is the groove made by the superior sagittal sinus. Here in the supratentorial part of the occipital bone is a concavity on either side for the occipital pole of the cerebral hemisphere. At the internal occipital protuberance the sagittal groove turns to one side (usually the right) into the transverse groove along the roof of the posterior fossa. The other transverse groove (usually the left) is narrower; it begins at the internal occipital protuberance by the inflow of the straight sinus. The transverse groove, straddled by the tentorium cerebelli, runs forward along the occipital bone to the inferior angle of the parietal and so to the mastoid part of the temporal. Here at the roof of the posterior fossa the groove for the superior petrosal sinus joins it. The *sigmoid groove*, continuous with the transverse groove, indents the cranial surface of the mastoid bone and a *mastoid foramen* often runs posteriorly from this part (p. 564). Lower down the sigmoid groove indents the jugular process of the occipital bone, and here the *condylar canal* runs back to open behind the occipital condyle. The *jugular foramen* (p. 572) is formed between the deep jugular notch of the petrous bone and the shallow jugular notch of the occipital bone. Right and left sides are seldom of equal size; the larger jugular foramen is almost always that which receives the superior sagittal sinus via the transverse and sigmoid sinuses, and this is more commonly the right one.

Running up from the foramen magnum to the dorsum sellae is a broad groove, the *clivus*. Just above

the foramen magnum each border of the groove shows a rounded prominence, the *jugular tubercle*. This is the line of fusion of the basiocciput and the lateral part of the bone. It lies above the occipital condyle, and between them the bone is perforated obliquely (almost transversely) by the *hypoglossal canal* (Fig. 6.94, p. 566). The hypoglossal nerve enters here as two roots (Fig. 6.96, p. 573). They are separated by a flange of dura mater that often ossifies. Between the jugular tubercles the clivus is occupied by the medulla, and the groove behind the jugular tubercle lodges the glossopharyngeal, vagus and accessory nerves on their way to the jugular foramen. Above the jugular tubercles the groove of the clivus broadens to indent the apex of each petrous temporal almost as far as the internal acoustic meatus; this broad groove lodges the pons. A glance into the posterior fossa will show the imprint of pons and medulla, with the jugular tubercle lying in the angle between them. Opposite the upper borders of the petrous bones the basiocciput and basisphenoid meet; the cartilaginous epiphysis between them (the sphenoccipital synchondrosis) ossifies at 25 years. The *groove of the inferior petrosal sinus* indents the adjacent margins of the basiocciput and temporal bones. The osteology of the petrous temporal bone in the posterior fossa is considered on page 572. Note especially the internal acoustic meatus, the glossopharyngeal notch in the jugular foramen and the opening of the aqueduct of the vestibule.

The *internal occipital crest* runs down in the midline from the internal occipital protuberance; to it is attached the narrow falx cerebelli over the occipital sinus. To either side of the internal occipital crest the deep concavities of the occipital bone lodge the cerebellar hemispheres; the external surface of this bone is covered by the insertions of the extensor muscles of the back of the neck.

OSSIFICATION OF THE SKULL

In the anterior fossa only the ethmoid ossifies in cartilage. The floors of the middle and posterior fossae ossify in cartilage. The rest of the skull ossifies in membrane. Details of ossification are noted in the following descriptions of individual bones.

PART 2 SKULL BONES

Most of the essential features of each bone have been seen in the study of the intact skull, but the new views

obtained by handling the separate bones complete the survey, and the *additional* features thus displayed are now to be described. Each bone should be orientated for study alongside an intact skull.

Frontal bone

Inspect the disarticulated bone from below. There is a deep *ethmoid notch* between the concave orbital roofs. Alongside the notch the lower surface of the orbital plate shows fossae indented by the upper limits of the ethmoid sinuses, and anterior to these the frontal sinus opens (Fig. 8.6). Note that the rough mark for the trochlea in the roof of the orbit lies below the floor of the frontal sinus. The *foramen caecum* in the anterior cranial fossa, at the lower limit of the frontal crest, is now seen to be a blind pit; only in 1% does it perforate the frontal bone.

Trace the edge-to-edge articulation of adjacent skull bones. The nasal bone and frontal process of the maxilla articulate side by side over a wide area of rough bone which projects down medial to the superior orbital margin. Behind this is the area of ethmoid sinus indentation, with the oblique groove for the anterior ethmoidal nerve and the transverse groove for the posterior ethmoidal nerve crossing between the fossae. This area fits like a lid over the lateral mass of the ethmoid. The cribriform plate of the ethmoid fills

the ethmoid notch. The lesser wing of the sphenoid articulates along the posterior border of the orbital roof. Lateral to this is a broad rough area for the greater wing of the sphenoid. The lateral margin of the orbit is completed in front by the zygomatic bone. The posterior border of the *squamous part* of the frontal bone, pitted by the diploë, articulates above the greater wing of the sphenoid with the parietal bone. The meeting place of the three bones is the pterion.

Ossification. Ossification is wholly in membrane. A centre appears above each orbital margin and the bone develops in two halves. The metopic suture between them usually unites in the second year but may persist.

Sphenoid bone

Take the opportunity of noting certain features not visible in the intact skull. The greater wing and pterygoid process project from a common junction with the lower part of the body. The **pterygoid canal** perforates the root of the pterygoid process. It is almost as large as the foramen rotundum in the nearby greater wing, but lies lower and more medial, *in line with the medial pterygoid plate* (Fig. 8.7). Its posterior aperture can now be confirmed as lying between the lingula and the pterygoid tubercle. The smooth area of the pterygoid process below these foramina is the posterior wall of the *pterygopalatine fossa*. The rough area below this opens into

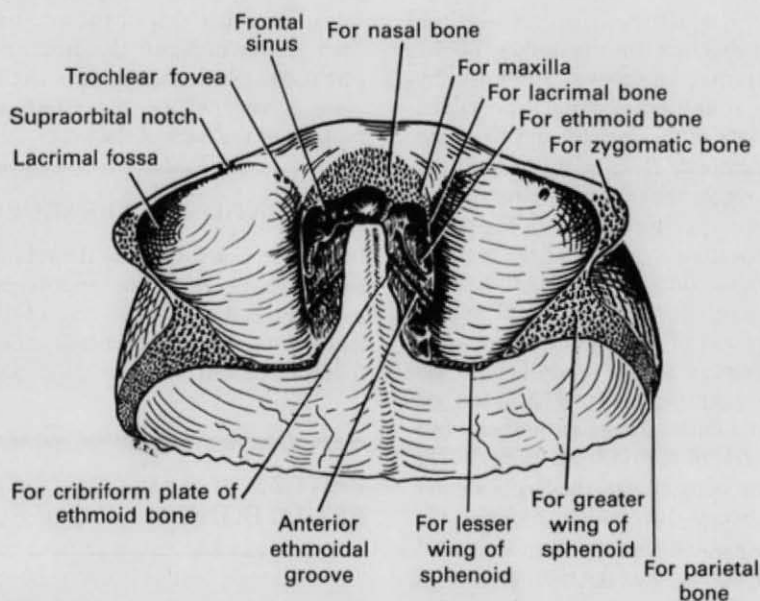


Fig. 8.6 Frontal bone from below.

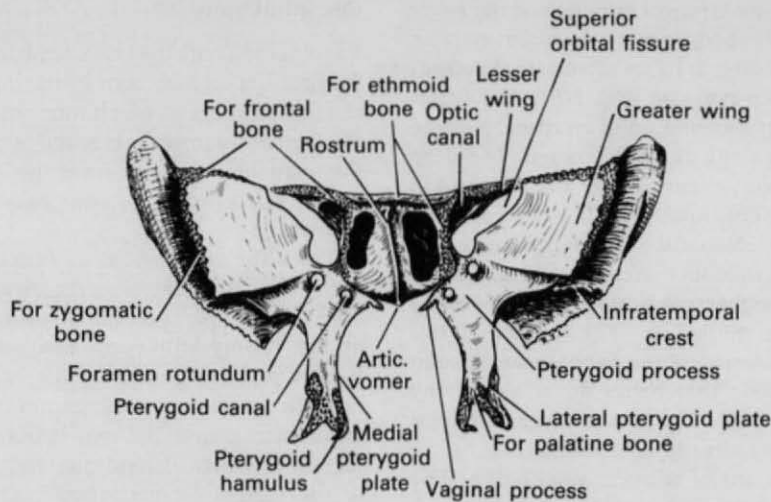


Fig. 8.7 Sphenoid bone from the front.

the pterygoid notch between the lower ends of the pterygoid plates; the pyramidal process of the palatine bone articulates here. The perpendicular plate of the palatine bone articulates with the medial pterygoid plate to form the medial wall of the pterygopalatine fossa. The *vaginal process* of the medial pterygoid plate is grooved at the base of its lower surface; the palatine bone extends up to cover this groove and convert it into the palatovaginal canal. The body of the sphenoid shows an inferior ridge for the ala of the vomer, which fits under the vaginal process. The front of the body of the sphenoid is projected into the prominent *rostrum*, which articulates with the perpendicular plate of the ethmoid at the upper part of the nasal septum far back. The rostrum is projected back into the body as a septum between the two sphenoidal air sinuses; the septum is always deviated. The sinuses can be inspected through their anterior apertures; much of the thin anterior bone (formed by the sphenoidal conchae) is usually destroyed during disarticulation. The sinuses excavate the bone to a very variable extent, seen better in a sagittal section of the skull.

Trace the articulations of adjacent skull bones. Posteriorly the body (here called basisphenoid) articulates with the basiocciput at the spheno-occipital synchondrosis which ossifies at the twenty-fifth year. The straight posteromedial border of the greater wing lies near the apex of the petrous bone at the foramen lacerum. It is grooved for the cartilaginous part of the auditory tube. The curving posterolateral border articulates with the squamous temporal bone by a bevelled suture that slants between the two bones. In the

infratemporal fossa at the base of the skull the greater wing overlies the squamous part, in the temporal fossa on the side of the skull the squamous part overlaps the greater wing. The upper border of the greater wing articulates with the parietal and frontal; the frontal articulation extends medially to bridge the superior orbital fissure between greater and lesser wings. The optic canal perforates the base of the lesser wing; medial to this the ethmoid labyrinth articulates. The anterior border of the greater wing articulates with the zygomatic bone. The articulations with the vomer and palatine bone have been noted.

Ossification. The floors of the middle and posterior cranial fossae ossify in cartilage. Bone above and below this (cranial vault and face) ossifies in membrane. Accordingly the body, lesser wing, and base of the greater wing ossify in cartilage. The rest of the greater wing and the pterygoid plates ossify in membrane. Centres appear at the end of the second month, and it serves no practical purpose to attempt to memorize them.

Temporal bone

The features not visible in the intact skull should be noted. The petrous part is perforated by the *carotid canal*, in which the internal carotid artery bends through a right angle. The aperture of exit lies well to the lateral side of the apex, in the foramen lacerum. Behind this, on the lateral surface, the petrous bone is perforated by the *musculotubular canal*, divided horizontally by a thin bony septum into the upper

semicanal for the tensor tympani muscle, and the lower semicanal which is the bony part of the auditory tube. The whole canal is roofed in by an extension of petrous bone from the tegmen tympani (Fig. 8.8). The flange curves down between squamous and tympanic parts to reach the base of the skull, as already noted. The deep *jugular notch* lodges the jugular bulb. It and the bend in the carotid canal lie very close to the floor and anterior wall of the middle ear. Note the external opening of the *cochlear canaliculus* (aqueduct of the cochlea) in the depths of the glossopharyngeal notch. The *internal acoustic meatus* can be studied (p. 572), and behind this the opening of the *aqueduct of the vestibule* can be seen under a flange of bone that hangs down like a tiny curtain (Fig. 6.94, p. 566). The middle ear (p. 526) and labyrinth (p. 531) have already been studied.

Trace the articulations of adjacent skull bones. The apex of the petrous part is lodged between basiocciput and greater wing of sphenoid as far as the foramen lacerum (Fig. 8.4). The bevelled and serrated edge of the squamous part articulates in front with the greater wing and above with the parietal bone, which it widely overlaps. Posteriorly the mastoid part articulates with the parietal and occipital bones. The suture at the tip of the zygomatic process is very oblique.

Ossification. The petromastoid part, in the skull base, ossifies in cartilage at the middle of pregnancy. The styloid process (not skull, but second pharyngeal arch) begins to ossify at the end of pregnancy. The membrane parts of the bone (squamous and tympanic) ossify at the eighth embryonic week. Subsequent growth is described on page 47.

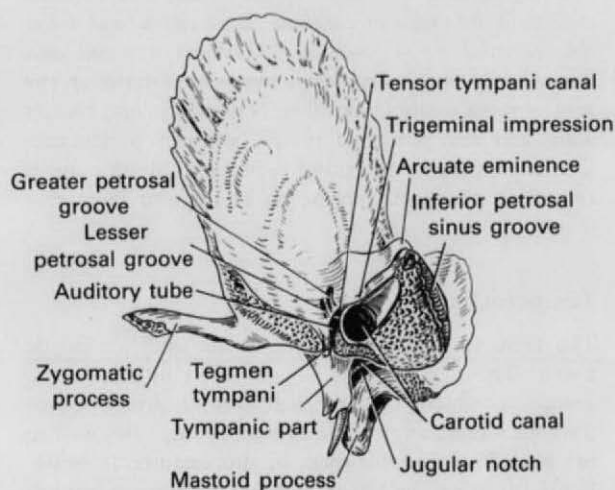


Fig. 8.8 Right temporal bone, looking directly at the apex to show the opening of the bony part of the auditory tube.

Occipital bone

Examination of the disarticulated bone shows no features not already seen in the intact skull. Note that the jugular process, which forms the posterior border of the jugular foramen, is grooved in the posterior fossa by the sigmoid sinus and from this groove the condylar canal (when present) passes back above the occipital condyle.

Trace the articulations of adjacent skull bones. The basiocciput articulates, on the clivus, with the basisphenoid by the spheno-occipital synchondrosis that ossifies at the twenty-fifth year. Along each border of the basiocciput is a groove for the inferior petrosal sinus; here the apical part of the petrous temporal articulates. Below the groove the two bones part to enclose the jugular foramen. Behind the foramen the mastoid part of the temporal bone articulates, and above this the parietal bone meets the occipital up to the lambda.

Ossification. According to the pattern (the base of the skull ossifies in cartilage), only the apical portion of the squamous part, above the highest nuchal line, ossifies in membrane. There are four other centres. All centres appear at the end of the second month. The basiocciput (one centre) joins each (lateral) jugular part (one centre), by a cartilaginous epiphysis across the occipital condyle and jugular tubercle at the hypoglossal canal. The squamous part is a combination of cartilaginous and membrane bones which join very quickly; failure of union results in a separate 'interparietal bone' below the lambda. The squamous part, so formed, meets the pair of jugular parts along a cartilaginous junction that forms a posterior tangent to the foramen magnum (Fig. 8.9). Thus at birth the occipital bone is in four parts; basiocciput, a pair of jugular parts, and the squamous part. The squamous fuses with the pair of jugulars at the end of the second year, when the milk dentition is complete. The pair of jugular parts fuse with the basiocciput (across the condyles) at the sixth year, when the permanent dentition begins to erupt. The basiocciput fuses with the basisphenoid at the twenty-fifth year, when the permanent dentition is complete. Thus the backward elongation of the palate to accommodate the teeth is matched by a compensating growth of the skull base to keep the nasopharynx patent.

Parietal bone

The isolated bone exposes the diploë along the anterior, superior and posterior margins. The inferior margin is sharply bevelled where it is overlapped superficially by the squamous temporal. Thus can the isolated bone be

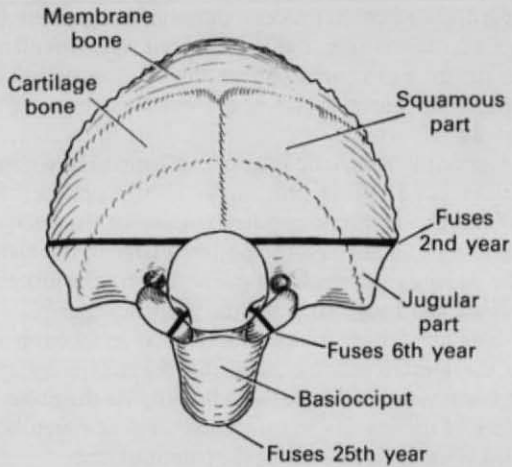


Fig. 8.9 Occipital bone from below at birth, showing the four parts.

placed in the anatomical position. To distinguish right from left the groove in the posteroinferior angle made by the sigmoid sinus may help, but much more useful is to glance at the grooves made by the middle meningeal vessels. The anterior branch grooves the bone just behind the anterior border, while branches of the posterior division make grooves that pass up and *back* towards the posterior border. The articulations with adjacent bones can be checked in the intact skull. The upper border articulates with the other parietal at the sagittal suture. The anterior border articulates with the frontal at the coronal suture. The anteroinferior angle articulates with the sphenoid, and the bevelled inferior border is overlapped by the squamous part of the temporal. The posteroinferior angle shows on its internal surface a fragment of the groove for the transverse sinus, and meets the mastoid part of the temporal, and the posterior border articulates with the occipital at the lambdoid suture.

Ossification. The bone ossifies in membrane before the eighth week; the centre appears at the site of the future parietal eminence.

Ethmoid bone

The ethmoid consists of a pair of lateral masses complicated enough to have earned the name of labyrinth. They are joined above by the cribriform plate, in the floor of the anterior cranial fossa. From the midline of the cribriform plate the crista galli projects up and the perpendicular plate projects down.

Each **labyrinth** is a thin-walled box, approximately rectangular. Anteriorly the wall is deficient and is

completed by incorporation of part of the lacrimal bone. A similar posterior deficiency is made good by the sphenoidal concha and the orbital process of the palatine bone. The labyrinth has no roof of its own; it is overlapped by the orbital part of the frontal bone, which articulates edge to edge with the cribriform plate. The cavity of the labyrinth is occupied by air cells, whose walls are undulating flakes of paper-thin bone. A partition near the anterior end of the labyrinth makes a funnel-shaped cavity, the *infundibulum*, beneath that part of the roofing frontal bone which contains the frontal sinus. The infundibulum is open at the lower border of the labyrinth; its lining mucous membrane, forming the *frontonasal duct*, thus leads from the frontal sinus through the ethmoid to the middle meatus of the nose. The infundibulum may be regarded as a specialized anterior ethmoidal air cell. The lateral wall of the labyrinth, paper thin, is the orbital plate or *lamina papyracea*. It can be seen in the medial wall of the orbit. The medial surface of the labyrinth is irregular. It can be inspected in a sagittal section of the skull. The *superior* and *middle nasal conchae* spring from a common stem and diverge from each other posteriorly. The middle concha is larger of the two, and it projects anteriorly to articulate with the frontal process of the maxilla and posteriorly to articulate with the perpendicular plate of the palatine just below the sphenopalatine foramen. The middle ethmoidal air cells project as the bulla, under cover of the overhanging middle concha. The lower border of the labyrinth articulates with the upper edge of the maxillary hiatus. The *uncinate process* curves down in front of the bulla, across the maxillary hiatus, to articulate with the inferior concha. The anterior ethmoidal air cells open just behind the infundibulum; if the bone is incomplete the infundibulum itself serves for them as well as for the frontal sinus. The middle ethmoidal air cells open on the bulla and the posterior cells open below the superior concha. The crista galli (p. 653), cribriform plate (p. 653) and perpendicular plate (p. 473) have already been studied.

The articulations of the labyrinth have been noted. The perpendicular plate, in the nasal septum, articulates anteriorly with the frontal and nasal bones, inferiorly with the septal cartilage, and posteriorly with the vomer and rostrum of the sphenoid (Fig. 6.22, p. 472).

Ossification. The ethmoid ossifies in the cartilage of the nasal capsule. The labyrinth begins to ossify at the fifth month and the process is complete before birth. The cribriform plate, crista galli and perpendicular plate are still cartilaginous at birth and begin to ossify about the first year.

Maxilla

The features to be noted in the disarticulated bone are on its medial and posterior surfaces. All the other features have been inspected in the intact skull. Through the *hiatus* in its nasal wall the thin-walled body can be seen to contain the sinus, which tapers to its apex in the zygomatic process. Sometimes the sinus has excavated through the maxilla into the zygomatic bone (Fig. 8.10). Note now that the floor of a large sinus dips into the alveolar process and lies lower than the level of the palatine process. The roof and anterior wall of the sinus show a ridge projecting down from their junction; this is made by the infraorbital nerve in its canal. The outlines of the anterior and middle superior alveolar canals can usually be seen through the eggshell thin bone by transillumination. The upper border of the maxillary hiatus is at the floor of the orbit; often this thin edge of bone is here and there prised apart into two layers by excavation from the adjacent ethmoid air cells. The upper and anterior edges of the hiatus meet at a tongue-like process that protrudes forwards over the *lacrimal groove*. This groove, wide and deep, is overlapped from in front by the base of the frontal process. The groove is directed down and somewhat back, and its concave floor makes a convex elevation on the medial wall of the sinus in front of the

hiatus. The frontal process shows a roughened low ridge across its base, the *conchal crest*, for articulation with the inferior concha. Above this is a less prominent ridge for the anterior end of the middle concha of the ethmoid.

Inspect the roughened areas that articulate with the palatine bone. Below the hiatus is an approximately square area for the perpendicular plate of the palatine. Behind this, and behind the posterior edge of the hiatus, is the sloping *greater palatine groove*. Behind the groove is an elongated rough strip for the perpendicular plate of the palatine, which bridges the groove and converts it into the greater palatine canal (for the greater palatine nerve and vessels). Above the tuberosity on the posterior surface of the maxilla is a triangular area of rough bone for the pyramidal process of the palatine bone.

The palatine process articulates with that of the opposite maxilla. The articulating surface is roughened by vertical ridges and grooves, and is projected up into a *nasal crest* for articulation with the vomer. Anteriorly it is grooved by the large *incisive canal*, which slopes down and forwards. The canal transmits the nasopalatine nerves, and the greater palatine arteries run upwards through it to the septum.

Trace the articulations with adjacent bones. The anterior margin of the frontal process has a narrow groove for the nasal bone. The apex of the frontal process is expanded and very rough for articulation with the frontal bone. The posterior border of the frontal process articulates with the lacrimal bone. The lacrimal bridges the lacrimal groove to articulate with the tongue-like process at the upper angle of the hiatus. The lower edge of the lacrimal bone articulates with the inferior concha, which bridges the lacrimal groove and completes its conversion into the nasolacrimal canal. The ethmoidal labyrinth articulates with the upper edge of the maxillary hiatus. The orbital process of the palatine bone articulates posteriorly between ethmoid and maxilla and lies at the apex of the floor of the orbit. The remainder of the articulation with the palatine bone (vertical and horizontal plates and pyramidal process) has already been noted.

Ossification. The maxilla is wholly a membrane bone. The cartilaginous nasal capsule (p. 43) is only a scaffolding for membrane bone (like Meckel's cartilage). A primary centre appears in the body of the maxilla, above the canine fossa, at the sixth week. The premaxilla ossifies a week later; this bone is overlapped by bone from the primary centre (Fig. 1.38, p. 43).

Palatine bone

This delicate bone is the key to the understanding of

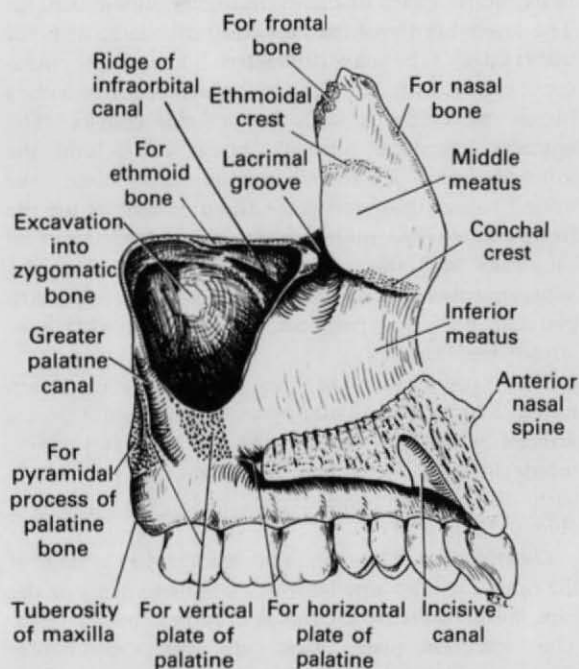


Fig. 8.10 Left maxilla from the medial side.

the pterygopalatine fossa and some of the canals that lead therefrom. Basically the shape is simple: a flat plate of bone is bent at a right angle in the form of a small *horizontal plate* (the back of the hard palate) and a larger *perpendicular plate* (in the lateral wall of the nose) and a *pyramidal process* (formerly called the tubercle) that projects posteriorly from the angle of junction of the plates. The base of the pyramidal process is at the junction of the plates, and from here the process tapers laterally and downwards to be slotted between the maxilla and the pterygoid plates of the sphenoid (Fig. 6.11, p. 448). It plugs the gap between the diverging lower ends of the medial and lateral pterygoid plates (Fig. 8.7) and it likewise articulates with a rough surface just above the tuberosity of the maxilla. An uncritical glance at a skull might suggest that the pterygoid plates articulate with the maxilla, but the pyramidal process of the palatine intervenes (Fig. 8.10). In a young skull, before ossification of these sutures, a separate triangular surface can be seen between the tuberosity of the maxilla and the lateral pterygoid plate. The superficial head of the medial pterygoid arises here. Similarly there is a bare area of the pyramidal process facing posteriorly between the lower ends of the pterygoid plates (Fig. 8.11) and the deep head of the medial pterygoid muscle extends down to arise from this surface.

The **horizontal plate**, articulating with the palatine process of the maxilla, meets its twin in the midline of the hard palate, and this border of the bone is marked by an upraised *nasal crest* for articulation with the vomer (like the nasal crest of the palatine process of the

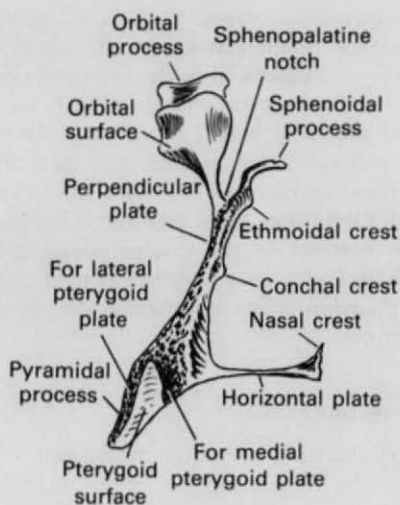


Fig. 8.11 Left palatine bone from behind.

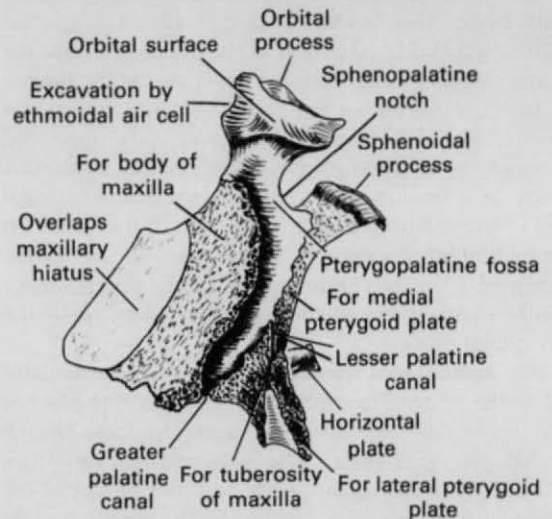


Fig. 8.12 Left palatine bone from the lateral side.

maxilla). The posterior border of the horizontal plate is concave and projects back to the midline of the hard palate as the *posterior nasal spine*. The inferior surface is usually marked by the *palatine crest*. This begins at the base of the pyramidal process, and is prominent here, at the posterior boundary of the greater palatine foramen. The crest curves back to the posterior nasal spine, becoming gradually less prominent. The palatine aponeurosis is attached to the crest, and the upper head of palatopharyngeus (including fibres that contribute to Passavant's ridge) arises from the smooth area between the crest and the posterior border. The base of the pyramidal process, behind the crest, is perforated by one or two *lesser palatine foramina*. The greater and lesser palatine foramina give exit to their respective nerves and vessels.

The **perpendicular plate** articulates with the body of the maxilla and with the medial pterygoid plate; it spans the gap between these two bones, and thus forms the medial wall of the pterygopalatine fossa. It is projected up into two *processes*, *orbital* and *sphenoidal*, with a deeply rounded *sphenopalatine notch* between them. The *lateral surface* can be inspected only in a carefully disarticulated bone; it is largely occupied by its articulation with the maxilla (Fig. 8.12). If the maxilla has already been studied it will easily be appreciated that the perpendicular plate of the palatine not only overlaps the posterior part of the maxillary hiatus (Fig. 8.10) but is applied to the body of the maxilla below and behind this. The posterior part of the maxillary surface shows the gradually deepening *greater palatine groove*, almost closed below by the approaching

bony ridges that border it (Fig. 8.12). The greater palatine groove fits over that of the maxilla to form the *greater palatine canal*. From the lower part of the greater palatine groove one or two *lesser palatine canals* perforate the base of the pyramidal process. At the upper end of the greater palatine groove, below the sphenopalatine notch, is a smooth area which constitutes the medial wall of the pterygopalatine fossa. The strip of bone on the pyramidal process that articulates with the medial pterygoid plate is continued up along the posterior border of the perpendicular plate to merge into the sphenoidal process.

The **sphenoidal process** (Fig. 8.11) articulates below the body of the sphenoid. It is a curled plate of thin bone that overlaps the vaginal process of the medial pterygoid plate. The palatovaginal canal lies between them and opens at the posterior border of the sphenoidal process. The canal transmits the pharyngeal branch of the pterygopalatine ganglion and a corresponding branch of the maxillary artery.

The **orbital process** is roughly pyramidal in shape, attached by its apex to the perpendicular plate. It lies against the maxilla and extends below the posterior end of the ethmoid labyrinth to form a triangular apex to the floor of the orbit. It is usually excavated by extension into it of a posterior ethmoidal air cell. The lower part of the ethmoid with which the orbital process articulates is the original sphenoidal concha (see p. 657). This articulation converts the sphenopalatine notch into the **sphenopalatine foramen**, which is a communication between the pterygopalatine fossa and the nose. It transmits the posterior superior nasal and nasopalatine nerves and vessels and the sphenopalatine artery, and is closed over in life by the mucous membrane of the lateral wall of the nose, immediately behind the posterior end of the middle concha.

The *medial surface* of the perpendicular plate can be seen in the intact skull. It forms part of the lateral wall of the nose. Halfway up is the *conchal crest* for articulation with the inferior concha. Just below the sphenopalatine foramen is the *ethmoidal crest* for articulation with the posterior end of the middle concha (Fig. 6.22B, p. 472).

The articulations with adjacent bones have been noted in the above survey. The **pterygopalatine fossa** will now be understood. Its medial wall is the perpendicular plate of the palatine. The anterior wall is the body of the maxilla above the tubercle, and the posterior wall is the root of the pterygoid process and greater wing of the sphenoid. The roof of the fossa is the body of the sphenoid.

Ossification. In common with the bones of the facial skeleton, the palatine ossifies in membrane. A centre appears at the seventh week, in the pyramidal

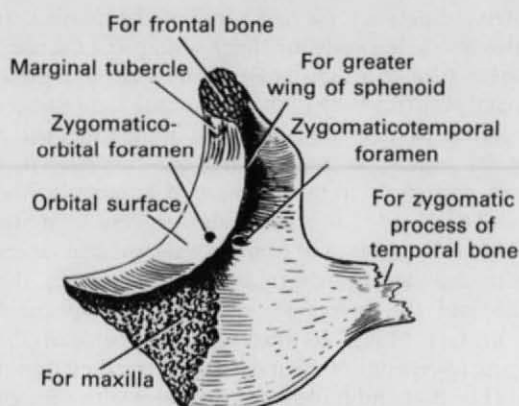


Fig. 8.13 Right zygomatic bone from the medial side.

process, and bone spreads from this over the surface of the cartilaginous nasal capsule (p. 43).

Zygomatic bone

Inspection of the intact skull shows all the features except the articular surfaces. The maxillary surface is the most extensive of these, and it may be excavated by extension of the maxillary sinus.

Ossification. The bone ossifies in membrane at the eighth week. There are three centres; they fuse at mid-term. Failure to fuse results in three or two parts to the bone. It is very often in two parts in the Japanese.

Nasal bone

The disarticulated bone shows a broad upper end with an extensive rough surface for articulation with the frontal bone. In the midline the two nasal bones articulate with each other and with the perpendicular plate of the ethmoid. The lateral border articulates with the frontal process of the maxilla. The inferior border is free at the bony margin of the nose, but in life it articulates with the lateral nasal cartilage. This border of the bone is notched by the external nasal nerve, which grooves the concave nasal surface of the bone.

Ossification is in membrane at the eighth week of pregnancy.

Lacrimal bone

This delicate bone lies in the medial wall of the orbit, between the frontal process of the maxilla and the labyrinth of the ethmoid. It overlaps the anterior ethmoidal air cells and lies edge to edge with the orbital

plate of the labyrinth. It extends up to articulate with the frontal bone. Its orbital surface is projected into the vertical *posterior lacrimal crest*. In front of the crest lies the fossa for the lacrimal sac. The lower end of the posterior lacrimal crest is projected forwards as the *hamulus*; this spans the lateral margin of the lacrimal fossa to articulate with the maxilla at the upper end of the nasolacrimal canal (Fig. 6.93, p. 565). The medial wall of this canal is continued by the *descending process* of the lacrimal bone, which articulates with the inferior concha in the lateral wall of the nose.

Ossification occurs in membrane soon after the eighth week.

Inferior nasal concha

This scroll-like bone is thicker than the delicate ethmoidal conchae. At the middle of its curved upper border a vertical flange projects down as the *maxillary process* to overlap the lower part of the hiatus in the maxilla. In front of this the sharp upper border articulates with the conchal crest on the frontal process of the maxilla, spanning the lacrimal groove. The lacrimal bone articulates with it here, and the two together form the medial bony wall of the nasolacrimal canal. The uncinate process of the ethmoid articulates with the upper border of the concha across the maxillary hiatus. Behind the hiatus the upper border of the concha articulates with the conchal crest on the perpendicular plate of the palatine bone.

Ossification is in the cartilage of the nasal capsule; the centre appears at about mid-term.

Vomer

This is a flat plate in the form of a ploughshare. It rests on the nasal crests of the maxillae and palatine bones, and its upper border articulates in front with the septal cartilage and behind with the perpendicular plate of the ethmoid bone (Fig. 6.22, p. 472). Its oblique posterior border is free at the posterior limit of the nasal septum. Above this the upper border is expanded into a pair of *alae* which are slotted against the sphenoid, between the body of the bone and the vaginal processes. Each surface of the bone shows an oblique groove made by the sphenopalatine vessels and nasopalatine nerve. The vomer is commonly deviated from the midline; here and there it may be separated into two laminae.

Ossification is in membrane at the eighth week. A centre appears on either side of the cartilaginous septum and two plates are formed, with a layer of cartilage between them (see p. 43).

MANDIBLE

The **mandible** (Fig. 8.14) consists of a body which carries the teeth (deep to this part lies the cavity of the mouth) and a ramus which is for articulation and the insertion of jaw-moving muscles (deep to this part lies the infratemporal fossa).

The **body** of the mandible is projected up around the teeth as alveolar bone which forms the walls of the tooth sockets. The alveolar bone is covered by mucoperiosteum to form the inner and outer gums (*gingivae*). The cavity of the tooth socket gives attachment to the periodontal ligament; loss of this fibrous tissue in the dried skeleton commonly allows the teeth to rattle in the bone. Healthy teeth will not fall out the dried mandible, for the alveolar bone is constricted somewhat about their necks. After loss of a tooth the living alveolar bone atrophies and the bottom of the socket fills up with new bone; thus a glance at a gap will tell whether the tooth was lost before or after death.

On the **outer surface** of the body the sharp anterior border of the ramus extends forward as the *external oblique ridge*. The buccinator is attached along this ridge as far as the anterior border of the first molar tooth. Farther forward depressor labii inferioris and depressor anguli oris arise respectively in front of and just below the mental foramen. Nearer the midline, just above the mental protuberance, mentalis and the mental slips of orbicularis oris arise from this level. Below the gums the mucous membrane of the vestibule extends down to this line of muscle origin, whence it is reflected to line the cheek and lip. The **mental foramen** lies halfway between upper and lower borders (see p. 49 for changes with age). Its position varies with respect to the teeth; it is usually between the two premolars. It faces backwards and slightly upwards.

The **lower border** of the body near the midline shows the shallow oval *digastric fossa*, for the attachment of the anterior belly of digastric. The lower border of the mandible gives attachment to the investing layer of deep cervical fascia from the midline back to the angle; the attachment is interrupted at the anterior border of masseter for the passage of the facial vessels and the marginal mandibular branch of the facial nerve, which lies on them here.

The lateral surface of the **ramus** gives insertion to masseter from the *angle* forwards along the lower border to the body behind the external oblique ridge as far as the second molar tooth (Fig. 6.14, p. 455). Oblique ridges in the area of insertion of the muscle may roughen the region of the angle. Above this the masseter is attached over the ramus almost as high as the *mandibular notch* (p. 454), the downward concavity

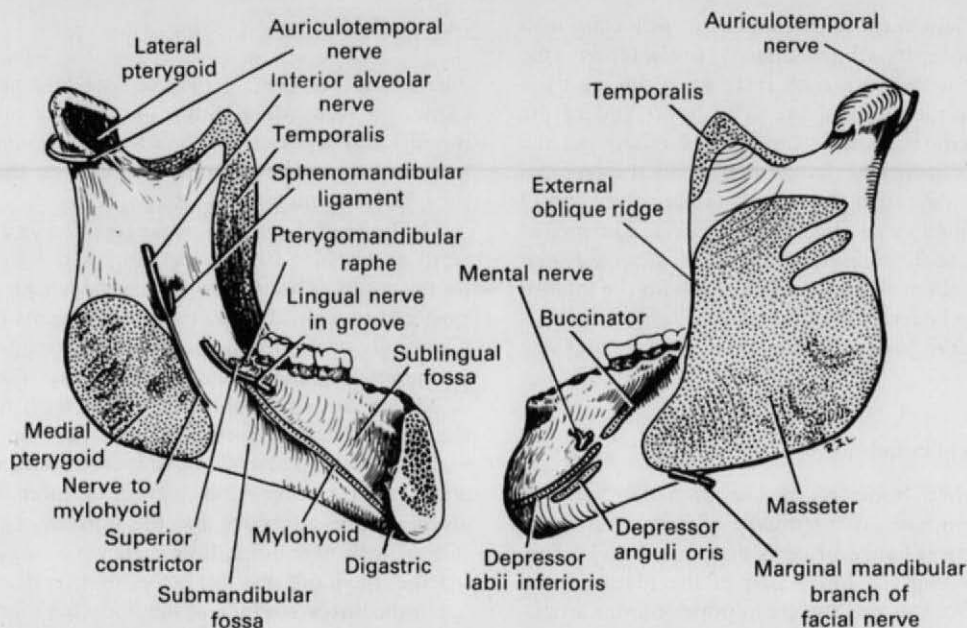


Fig. 8.14 Left half of the mandible from the medial and lateral sides, showing adjacent nerves and muscle attachments.

between the coronoid process in front and the condyle behind. The posterior border of the ramus is projected up as the neck, which expands into the *head* of the bone; the head and neck together form and the *condyle* or condylar process. The coronoid process, sharp-bordered, has a slightly concave lateral surface. The temporalis is attached here by tendinous fibres that overlap the margins somewhat (Fig. 6.14, p. 455). The sharp anterior margin of the ramus, slightly concave and properly known as the *coronoid notch*, is commonly called by dental clinicians the *external oblique ridge* and is continued on to the outer surface of the body (see above).

The **inner surface** of the body is characterized by the **mylohyoid line** which forms a prominent obliquity below the molar teeth and fades out as it passes forward below the mental spines (previously called genial tubercles). The attachment of mylohyoid along this line divides the mouth from the neck. The muscle extends from level with the posterior border of the last molar tooth to the midline between the mental spines and the digastric fossae; it may leave no mark here near the midline. The **mental spines** form four or less sharp projections low down in the midline; genioglossus arises from the upper and geniohyoid from the lower spines. Below the alveolar bone of the gums the mucous membrane of the mouth cavity lines the mandible down to the mylohyoid line and the mental spines. Above the anterior end of

the mylohyoid line is a smooth concavity, the *sublingual fossa*, which lodges the sublingual gland, and here the mucous membrane loses contact with the mandible to be draped over the upper part of the gland. Below the prominence of the mylohyoid line (i.e. in the neck) the elongated smooth *submandibular fossa* lodges the superficial part of the submandibular gland. Above the mylohyoid ridge the medial surface of the mandible is grooved below the last molar tooth by the lingual nerve, and above this groove the pterygomandibular raphe and superior constrictor are attached level with the posterior border of the last molar tooth (Fig. 6.26A, p. 486). The buccinator origin crosses the upper border of the mandible behind the last molar.

The medial surface of the **ramus** is characterized by the **lingula**, a sharp tongue of bone pointing towards the head of the mandible. It lies in front of the **mandibular foramen**, halfway between anterior and posterior borders of the ramus, and level with the occlusal surfaces of the teeth. The sphenomandibular ligament is attached to the lingula and to the lower margin of the foramen behind it. The ligament is pierced by the mylohyoid vessels and nerve and these lie in the **mylohyoid groove**, a narrow sulcus that runs down from the mandibular foramen to die out at the posterior end of the submandibular fossa. Between the mylohyoid groove and the angle of the mandible the medial pterygoid muscle is inserted, and irregular bony

ridges lie in this area for attachment of fibrous septa inside the muscle. The mylohyoid line, behind the last molar tooth, may be traceable upwards to the lingula and on to the head of the mandible, this bare bone forming a mechanical strut in the mandible. In front of this the anterior border of the ramus is bevelled from the tip of the coronoid process down to the area behind the last molar tooth (often unofficially called the retro-molar fossa) on the upper border of the body. The anterior boundary of the bevel is the sharp external oblique ridge (see above); the medial boundary, slightly more posterior, is the *internal oblique ridge* which is usually more rounded (a palpable landmark for inferior alveolar nerve block, p. 478). The posterior edge of the coronoid process is likewise bevelled down to the mandibular notch. Temporalis is inserted into these bevelled surfaces; the suprapericardial fibres of the muscle, sliding smoothly over the posterior pillar of the zygomatic arch, run forwards to their insertion along the posterior border of the coronoid process and are the only retractors of the head of the mandible. The vertical and anterior fibres of temporalis are inserted into the bevelled surface along the anterior border as far down as the buccinator behind the last molar tooth.

The **neck** of the mandible expands transversely into the **head**, which carries the articular surface. The sharp border of the mandibular notch curves up to the lateral end of the head, but the posterior border of the ramus curves up medially to the medial end of the head. Between these diverging borders the anterior surface of the neck is hollowed into the *pterygoid fovea* for the insertion of the lateral pterygoid. The posterior triangular area below the articular surface is smooth for the attachment of the lateral temporomandibular ligament. The **articular surface** is bevelled, with anterior and posterior sloping surfaces, and the transverse crest between them is directed medially and slightly backwards. The two condyles lie on the arc of a large circle which cuts across the front of the foramen magnum. The articular surface is covered by fibrocartilage identical in structure with the articular disc. The capsule and synovial membrane are attached to the articular margins.

Ossification. This membrane bone ossifies at the sixth week, in two halves around the scaffolding of Meckel's cartilage (p. 38).

The *growth* of the mandible is considered on page 49.

HYOID BONE

The **hyoid bone** lies free, suspended by muscle, and so is very mobile. The floor of the mouth and the tongue are attached to it above, and the larynx below, while

behind are attached the epiglottis and the pharynx. Furthermore, it provides an adjustable pulley for the digastric muscle. It is palpable in the living (feel your own).

The hyoid bone (Fig. 8.15) has a **body**, which is a curved sheet of bone convex forward and concave behind. On each side a **greater horn** projects back as a long slender process. At the junction of body and greater horn is the **lesser horn**, projecting up as a spike of bone (or hyaline cartilage) that does not always fuse but may remain permanently connected by fibrous tissue. Thus a U-shaped mass is produced, of a size that can be gauged by noting that it can be fitted inside the body of the mandible just above the mylohyoid line.

At rest the body lies just below the mandible, level with the last molar tooth, and the greater horn projects back as far as the angle of the mandible (Fig. 6.58, p. 524) at the level of C3 vertebra. This is the level of the lateral glossoepiglottic folds within the pharynx, bisecting the epiglottis. Thus the hyoid marks on the surface the junction of oropharynx and laryngopharynx (Fig. 6.28, p. 488).

The thyrohyoid membrane is attached to the sharp upper border of the body and greater horns, and hangs down free inside the curve of the bone. Behind the concave posterior surface of the body is a bursa between bone and membrane, and here the thyroglossal duct made an upward kink behind the bone (Fig. 1.32, p. 40). From the upper surface of the body and from the thyrohyoid membrane a rather fatty mass of loose fibrous tissue passes back to the epiglottis, the *hyoepiglottic ligament*. From the side of the epiglottis a flange of fibrous tissue passes across to the greater horn; covered with mucosa this constitutes the *lateral glossoepiglottic fold*. Attached to the lower border of the

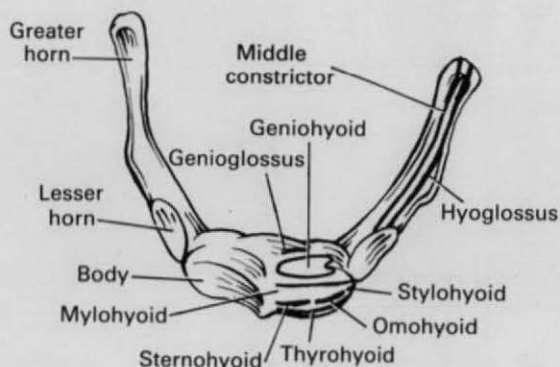


Fig. 8.15 Hyoid bone from above, with muscle attachments on the left side.

body is the upper attachment of the pretracheal fascia. In front of this sternohyoid and omohyoid are attached to a pair of concave fossae lying on the lower part of the anterior surface. Below omohyoid is the linear attachment of thyrohyoid, extending back to the lower border of the greater horn. Above these muscles the investing layer of deep cervical fascia has a linear attachment to the bone, which is thus subcutaneous and palpable along this line. Just above this line is the linear attachment of mylohyoid to the body of the bone, and above this is a deep pit for the insertion of geniohyoid. A few fibres of genioglossus may be fixed to the upper border of the body and to the lesser horn (chondroglossus) but they are insignificant. Fixation of the tongue to the hyoid bone is not attained by these fibres, but by hyoglossus along the greater horn.

The lesser horn gives attachment to the stylohyoid ligament, and the middle constrictor arises from it and from the whole length of the greater horn, thus anchoring the hyoid bone to the pharynx. Lateral to the constrictor hyoglossus arises from the whole length of the greater horn and the lateral part of the body alongside geniohyoid, thus anchoring the hyoid to the tongue. The base of the greater horn has a lateral boss of bone. Here is attached the fibrous sling through which the intermediate tendon of digastric glides freely, and this is straddled by the insertion of the split tendon of stylohyoid.

Ossification. Two centres for the body and one for each horn appear in the hyaline cartilage. Ossification occurs at about birth for the body and greater horn; the lesser horn ossifies during adolescence.

Biographical notes

Originally compiled by the late Jessie Dobson and based on her book *Anatomical Eponyms* (2nd edn 1962, Livingstone).

The use of eponymous names is frowned upon by many, not least because the accreditation does not necessarily give honour where honour is due. Despite their disappearance from official terminology, their use continues, because they bring back something of the fascination of discovery from days when a pair of eyes and a cerebral cortex were the only available tools, long before microchips and nanometers were ever dreamed of. The following notes will hopefully add a little human flesh to a historical skeleton.

ADAMKIEWICZ Albert (1850–1921) Professor of Pathology in the University of Krakow and later in Vienna.

Arterial supply of the spinal cord (p. 626)

ALCOCK Benjamin (1801–??) Graduate of the University of Dublin. In 1849 was appointed Professor of Anatomy in Queen's College, Cork, but was called upon to resign in 1853 in consequence of disputes about the working of the Anatomy Acts. Went to America in 1855 and was not heard of again.

Canal for the internal pudendal vessels in the ischioanal fossa (p. 404).

ARGYLL ROBERTSON Douglas Moray Cooper Lamb (1837–1909) Ophthalmic surgeon to Edinburgh Royal Infirmary from 1870 to 1897.

Pupil that reacts on accommodation but not to light (p. 519).

AUERBACH Leopold (1828–1897) Professor of Neuropathology in Breslau.

Myenteric nerve plexus of the gut (p. 329).

BABINSKI Joseph François Felix (1857–1932) Physician in Paris.

Extensor plantar response (p. 28).

BAILLARGER Jules François Gabriel (1809–1890) Neurologist and specialist in mental diseases at Charenton.

Bands in the cerebral cortex (p. 603).

BARTHOLIN Caspar (Secundus) (1655–1738) Succeeded his father, Thomas Bartholin, as Professor of Medicine, Anatomy and Physics at Copenhagen.

Greater vestibular glands of the female perineum (p. 412).

BEEVOR Charles Edward (1854–1968) London neurologist.

Sign of upward displacement of the umbilicus in lower abdominal paralysis (p. 29).

BELL Sir Charles (1774–1842) Edinburgh surgeon and anatomist who taught in Edinburgh and London and returned to Edinburgh to be Professor of Surgery.

Palsy of the facial nerve (p. 641).

BERRY Sir James (1860–1946) A Canadian from Kingston, Ontario, he became a surgeon at the Royal Free Hospital, London.

Suspensory ligament of the thyroid gland (p. 431).

BETZ Vladimir Aleksandrovich (1834–1894) Professor of Anatomy in Kiev from 1868–1889.

Giant pyramidal cells of the motor cortex (p. 603).

BIGELOW Henry Jacob (1818–1890) Professor of Surgery at Harvard University from 1849 to 1882.

Iliofemoral ligament of the hip joint (p. 167).

BOCHDALEK Victor Alexander (1801–1883) Professor of Anatomy in Prague.

Foramen of the lumbocostal trigone, congenital hiatus between the lumbar and costal parts of the diaphragm (p. 251).

BOWMAN Sir William Paget (1816–1892) Professor of Anatomy and Physiology at King's College, London, from 1848 to 1856. Leading ophthalmic surgeon in England.

Capsule surrounding the glomerulus in the kidney (p. 369), and anterior limiting membrane of the cornea (p. 517).

BROCA Pierre Paul (1824–1880) Professor of Clinical Surgery and Director of the Anthropological Laboratories in Paris.

Speech area of the cerebral cortex (p. 586).

BRODMANN Korbinian (1868–1918) German psychiatrist who became Professor of Anatomy at Tübingen.

Areas of the cerebral cortex (p. 586).

BROWN-SÉQUARD Charles Edouard (1818–1894) Born in Mauritius, he became Professor of Medicine at Harvard and later in Paris.

Syndrome of hemisection of the spinal cord (p. 627).

BRUNNER Johann Konrad (1653–1727) Professor of Anatomy at Heidelberg and, later, Strasbourg.

Submucosal glands of the duodenum (p. 330).

BUCK Gordon (1807–1877) New York surgeon.

Fascia of the penis (p. 408).

CALOT Jean François (1861–1944) French surgeon.

Triangle bounded by the common hepatic and cystic ducts and the liver (p. 349).

CAMPER Petrus (1722–1789) Professor of Medicine, Anatomy, Surgery and Botany in Groningen from 1763 to 1773.

Superficial fatty layer of the superficial fascia of the abdomen (p. 241).

CHASSAIGNAC Charles Marie Edouard (1805–1879) Surgeon in Paris.

Carotid tubercle on the sixth cervical vertebra (p. 440).

CLARKE Jacob Augustus Lockhart (1817–1880) Physician to the Hospital for Epilepsy and Paralysis, London. FRS 1854.

Dorsal nucleus of the spinal cord (p. 625).

CLOQUET Jules Germain (1790–1883) Professor of Anatomy and Surgery in Paris.

Lymph node in the femoral canal (p. 154).

COLLES Abraham (1773–1843) Professor of Anatomy and Surgery in Dublin from 1804 to 1836. FRS 1802.

Fracture of the lower end of the radius (p. 135), and superficial perineal fascia (p. 406).

COOPER Sir Astley Paston (1768–1841) Surgeon to St Thomas's and Guy's Hospitals, London.

Skin attachments of the breast (p. 71), and the pectineal ligament (p. 219).

CORTI Alfonso (Marquis) (1822–1888) Born in Sardinia. An eminent histologist who worked with Hyrtl, Johannes Müller, Kolliker, Gegenbaur and others, but held no academic post.

Organ of hearing (p. 535).

COWPER William (1666–1709) London surgeon. FRS 1698.

Bulbourethral glands (p. 406).

CUVIER Georges Leopold Chrétien Frédéric Dagobert (Baron) (1769–1832) The most eminent naturalist of his day, particularly noted as a zoologist and palaeontologist. Professor of Natural History, Paris.

Common cardinal veins in the embryo (p. 45).

DEITERS Otto Friedrich Karl (1834–1863) Professor of Anatomy and Histology at the University of Bonn.

Outer hair cells in the organ of Corti (p. 535).

DENONVILLIERS Charles Pierre (1808–1872) Professor of Anatomy and Surgery in Paris.

Rectovesical fascia (p. 394).

DESCEMET Jean (1732–1810) Professor of Anatomy and Surgery in Paris.

Posterior limiting membrane of the cornea (p. 517).

DOUGLAS James (1675–1742) Anatomist and 'man-midwife' of London. Physician to Queen Caroline, wife of George II. FRS 1706.

Rectouterine peritoneal pouch (p. 394), semicircular line of the rectus sheath (p. 297).

DUCHENNE Guillaume Benjamin Amand (1806–1875) An early specialist in neurology, he practised in Paris but held no hospital or university appointments.

Erb–Duchenne birth palsy of the upper brachial plexus (described by Erb) (p. 126).

DUPUYTREN Guillaume (Baron) (1777–1835) Professor of Surgery in Paris.

Contracture of the palmar aponeurosis (p. 107).

EDINGER Ludwig (1855–1918) Anatomist and neurologist of Frankfurt-am-Main. **WESTPHAL, Karl Friedrich Otto** (1833–1890) Professor of Psychiatry in Berlin.

Accessory nucleus of the oculomotor nerve (p. 607).

ERB Wilhelm (1840–1921) Professor of Medicine at Leipzig and, later, at Heidelberg, and considered to be one of Germany's greatest neurologists.

Erb's palsy due to traction injury of the upper brachial plexus (p. 126).

EUSTACHIO (EUSTACHI, EUSTACHIUS) Bartolomeo (1513–1574) Professor of Anatomy in Rome and Physician to the Pope.

Auditory tube (p. 530).

FABRICIUS Hieronymus (Girolamo Fabrizi of Aquapendente) (1533–1619) Professor of Surgery and Anatomy in Padua.

Bursa in chickens giving the name to B lymphocytes (p. 15).

FALLOT Etienne Louis Arthur (1850–1911) French physician. Professor of Hygiene and Legal Medicine in Marseilles.

Tetralogy of congenital heart defects (p. 276).

FOERSTER Otfried (1873–1941) Neurologist at the Psychiatric Clinic in Breslau.

Dermatomes (p. 24).

GALEN ? Claudius (130–200) Physician in Rome. For two years physician to the Emperor Marcus Aurelius in Venice.

Great cerebral vein (p. 603).

GENNARI Francesco (1750–1790) Physician and anatomist of Parma.

Stria of the visual area of the cerebral cortex (p. 587).

GIMBERNAT Manuel Louise Antonio don (1734–1816) Professor of Anatomy in Barcelona from 1762 to 1774. Surgeon to King Charles III of Spain.

Lacunar ligament (p. 297).

GIRALDÈS Joachim Albin Cardozo Cazado (1808–1875) Born in Oporto, Portugal. Professor of Surgery in Paris. Died as the result of a wound inflicted while conducting an autopsy.

Paradidymis (p. 309).

GRAAF Regnier de (1641–1673) Anatomist and physician of Delft.

Maturing ovarian follicle (p. 391).

GUYON Felix Jean Casimir (1831–1920) Genito-urinary surgeon and Professor of Surgical Pathology in Paris.

Canal for the ulnar nerve beside the pisiform bone (p. 107).

HARRIS Henry Albert (1886–1968) Professor of Anatomy in Khartoum and then at the University of Cambridge.

Mnemonic for facts about the spleen (p. 355).

HARTMANN Henry Albert Charles Antoine (1860–1952) Professor of Surgery in Paris.

Pouch in the neck of the gall bladder (p. 348).

HASSALL Arthur Hill (1817–1894) Physician and botanist. Practised in London and, later, the Isle of Wight.

Thymic corpuscles (p. 16).

HAVERS Clopton (1657–1702) London physician. FRS 1685.

Canals in bone (p. 8) and fat pads of joints (p. 12).

HEAD Henry (1861–1940) Neurologist. Physician to London Hospital. FRS 1899.

Dermatomes (p. 24).

HEISTER Lorenz (1683–1758) Professor of Anatomy and Botany in Altdorf and, later, Professor of Surgery and Botany in Helmstadt.

Spiral mucosal fold in the cystic duct (p. 350).

HENLE Friedrich Gustav Jakob (1809–1885) Professor of Anatomy in Göttingen from 1852 to 1885.

Narrow tubules of the kidney (p. 370).

HESELBACH Franz Kaspar (1759–1816) Surgeon and anatomist, Professor of Surgery at Wurzburg.

Inguinal triangle (p. 304).

HEUBNER Johann Otto Leonhard (1843–1926) Paediatrician in Berlin.

Recurrent branch of the anterior cerebral artery (p. 601).

HIGHMORE Nathaniel (1613–1685) Physician of Sherborne, Dorsetshire.

Maxillary sinus (p. 474).

HILTON John (1805–1878) Surgeon at Guy's Hospital, London from 1849 to 1871.

Joint innervation (p. 12), and discredited landmark in the anal canal (p. 403).

HIS Wilhelm (1863–1934) Professor of Anatomy successively at Leipzig, Basle, Göttingen and Berlin.

Atrioventricular bundle (p. 272).

HORNER Johann Friedrich (1831–1916) Professor of Ophthalmology in Zurich.

Syndrome due to damage to the cervical sympathetic nerves (p. 519).

HOUSTON John (1802–1845) Lecturer in Surgery in Dublin and physician to the City Hospital.

Internal rectal folds (p. 377).

HUMPHRY Sir George Murray (1820–1896) Professor of Anatomy at Cambridge until 1883 when he became the first Professor of Surgery there. First President of the Anatomical Society of Great Britain and Ireland.

Posterior meniscofemoral ligament of the knee joint (p. 182).

HUNTER John (1728–1793) London surgeon and anatomist. Founder of the Hunterian Museum now in the custody of the Royal College of Surgeons of England.

Adductor canal (p. 157).

HUNTER WILLIAM (1718–1783) Anatomist and surgeon of London. Brother of John Hunter.

Vascular circle of joints (p. 12).

HUSCHKE Emil (1797–1858) Professor of Anatomy in the University of Jena.

Tympanic foramen (p. 48).

JACOBSON Ludwig Levin (1783–1843) Anatomist and Physician in Copenhagen.

Tympanic branch of the glossopharyngeal nerve (p. 463).

KIESSELBACH Wilhelm (1839–1902) Professor of Otology at Erlangen.

Arterial anastomosis on the nasal septum (p. 472).

KILLIAN Gustav (1860–1921) Director of the Rhinolaryngological Clinic in Freiburg and, later, Berlin.

Dehiscence between the thyropharyngeus and cricopharyngeus parts of the inferior constrictor (p. 489).

KLUMPKE Augusta (Madame Dejerine-Klumpke) (1859–1927) An American from San Francisco, she studied in Lausanne and Paris and was one of the first women doctors. Described the birth paralysis while still a student with Joseph Jules Dejerine (later Professor of Neurology), whom she married.

Paralysis due to birth injury of the lower brachial plexus (p. 126).

KOCH Walter (1880–??) Physician and pathologist in Berlin and Freiburg, and pioneer of cardiac radiology.

Triangle marking position of SA node (p. 272).

KOCHER Emil Theodor (1841–1917) Professor of Clinical Surgery at Berne and winner of the Nobel Prize in 1909 for work on the thyroid gland.

Subcostal abdominal incision (p. 311) and mobilization of the duodenum (p. 351).

KUPFFER Karl Wilhelm von (1829–1902) Professor of Anatomy in Kiel (1867), Königsberg (1875) and Munich (1880).

Phagocytic cells of liver sinusoids (p. 347).

LANGER Karl (1819–1887) Professor of Anatomy in Vienna.

Cleavage lines of the skin (p. 3).

LANGERHANS Paul (1847–1888) Professor of Pathological Anatomy in Freiburg.

Endocrine islets of the pancreas (p. 353).

LATARGET André (1876–1947) Professor of Anatomy at Lyon from 1925.

Branches of the vagal nerve trunks along the lesser curvature of the stomach (p. 334).

LECOMTE O. (no dates known) Physician to the French Army in the nineteenth century.

Anconeus muscle (p. 96).

LEYDIG Franz von (1821–1908) Professor of Histology in Würzburg, Tübingen and Bonn.

Interstitial cells of the testis (p. 307).

LIEBERKÜHN Johann Nathanael (1711–1756) Physician and anatomist of Berlin, noted for his technique of injecting.

Intestinal crypts or glands (p. 330).

LISSAUER Heinrich (1861–1891) Neurologist in Breslau.

Dorsolateral tract of the spinal cord (p. 624).

- LISTER Joseph (Lord)** (1827–1912) Professor of Surgery in Glasgow (1860), Edinburgh (1869) and King's College, London (1877). Pioneer of antiseptic surgery.
Dorsal tubercle of the radius (p. 135).
- LITTLE James Laurence** (1836–1885) Professor of Surgery in Vermont.
Site of arterial anastomosis on the nasal septum (p. 472).
- LITTRÉ Alexis** (1658–1726) Surgeon and anatomist of Paris.
Glands of the penile urethra (p. 409).
- LOCKWOOD Charles Barrett** (1856–1914) Surgeon to St Bartholomew's Hospital, London. Founder of the *Journal of Anatomy and Physiology*.
Suspensory ligament of the eye (p. 511).
- LOUIS Pierre Charles Alexandre** (1787–1872) Physician of Paris.
Angle between manubrium and body of the sternum (named after, not by, him (p. 254).
- LUDWIG Wilhelm Friedrich** (1790–1865) Professor of Surgery and Midwifery in Tübingen. Court physician.
Submandibular cellulitis (p. 424).
- LUSCHKA Hubert** (1820–1875) Professor of Anatomy in Tübingen from 1849 to 1875.
Aperture in the lateral recess of the fourth ventricle (p. 613).
- McBURNIE Charles** (1845–1913) Professor of Surgery at the College of Physicians and Surgeons, New York.
Point indicating the position of the base of the appendix (p. 338), and abdominal incision (p. 311).
- MACKENRODT Alwin** (1859–1925) Professor of Gynaecology in Berlin. Also known as a pathologist.
Transverse cervical ligament of the uterus (p. 390).
- MAGENDIE François** (1783–1855) Professor of Pathology and Physiology in Paris and physician to the Hôtel Dieu.
Median aperture of the fourth ventricle (p. 613).
- MARSHALL John** (1818–1891) Fullerian Professor of Physiology at the Royal Institution; Professor of Anatomy at the Royal Academy; Professor of Surgery at University College London.
Oblique vein of the left atrium (p. 275).
- MAYO Charles Horace** (1865–1939) With his father and brother, founded a small hospital which developed into the Mayo Clinic, the world's largest private hospital.
Prepyloric vein (p. 333).
- MECKEL Johann Friedrich** (1724–1774) Professor of Anatomy, Botany and Gynaecology in Berlin.
Dural space for the trigeminal ganglion (p. 570).
- MECKEL Johann Friedrich** (1781–1833) Professor of Anatomy and Surgery in Halle. Grandson of the preceding.
Cartilage of the first branchial arch (p. 38), and ideal diverticulum (p. 326).
- MEIBOM Heinrich** (1638–1700) Professor of Medicine, History and Poetry in Helmstadt.
Sebaceous glands of the eyelids (p. 507).
- MEISSNER Georg** (1829–1905) Professor of Anatomy and Physiology in Basle and, later, Professor of Physiology in Göttingen.
Submucosal nerve plexus of the gut (p. 329).
- MÉNIÈRE Prosper** (1799–1862) Physician in Paris.
Disease of the inner ear with deafness, tinnitus and vomiting (p. 642).
- MONRO Alexander** (1733–1817) (Secundus) Succeeded his father Alexander Monro (Primus) as Professor of Anatomy in Edinburgh.
Interventricular foramen (p. 590).
- MONTGOMERY William Fetherstone** (1797–1859) Professor of Midwifery in Dublin.
Tubercles of the areola of the breast (previously described by and called tubercles of Morgagni) (p. 71).
- MORGAGNI Giovanni Battista** (1682–1771) Professor of Anatomy in Padua for 59 years, and considered to be the father of morbid anatomy.
Foramen, congenital hiatus between the sternal and costal parts of the diaphragm (p. 251).
- MORISON James Rutherford** (1853–1939) Surgeon to the Royal Infirmary, Newcastle-on-Tyne. Emeritus Professor of Surgery in the University of Durham.
Hepatorenal pouch of peritoneum (p. 316), and abdominal incision (p. 311).
- MULLER Johannes Peter** (1801–1858) Professor of Anatomy and Physiology in Berlin.
Paramesonephric duct (p. 309).

ODDI Ruggero (1845–1906) Physiologist of Perugia.

Sphincter of the hepatopancreatic ampulla (p. 350).

PACCHIONI Antoine (1665–1726) Professor of Anatomy in Rome and, later, Tivoli.

Arachnoid granulations (p. 559).

PACINI Filippo (1812–1883) Professor of Anatomy and Physiology in Pisa and the Professor of Histology in Florence.

Sensory end-organs (p. 317).

PANETH Joseph (1857–1890) Professor of Physiology in the Universities of Breslau and Vienna.

Cells at the base of intestinal crypts (p. 330).

PARKINSON James (1755–1824) Inherited his father's practice in the East End of London, and was a well-known palaeontologist.

Disease of basal nuclei (p. 607).

PARKS Sir Alan Guyatt (1921–1982) Surgeon to St Mark's Hospital and the London Hospital, and President of the Royal College of Surgeons of England from 1980 to 1982.

Structure of the anal canal (p. 401).

PARONA Francesco (1861–1910) Chief Surgeon to Novara Hospital, Italy.

Deep intermuscular space of the forearm (p. 92).

PASSAVANT Philipp Gustav (1815–1893) Surgeon of Frankfurt.

Ridge on the posterior pharyngeal wall during swallowing (p. 494).

PETIT Jean Louis (1664–1750) Began to learn anatomy at the age of 7 and when he was 12 was demonstrator of anatomy for Littré. When he was 16 he was appointed Surgeon to La Charité Hospital in Paris and finally became Director of the Academy of Surgery. FRS 1729.

Lumbar muscular triangle (p. 296).

PEYER Johann Conrad (1653–1712) Professor of Logic, Rhetoric and Medicine in Schaffhausen, Switzerland.

Aggregated lymphoid follicles in the lower ileum (p. 328).

PFANNENSTIEL Hermann Johannes (1862–1909) Gynaecologist in Breslau.

Transverse lower abdominal incision (p. 311).

POTT Sir Percival (1714–1788) Surgeon to St Bartholomew's Hospital.

Fracture of the lower end of the fibula (p. 229).

POUPART François (1661–1709) Surgeon to the Hôtel Dieu, Paris.

Inguinal ligament (p. 296).

PURKINJE Johannes Evangelista (1787–1869) Professor of Physiology in Breslau and, later, Prague.

Subendocardial fibres of the conducting system (p. 272), and cells of the cerebellar cortex (p. 618).

RANVIER Louis Antoine (1835–1922) Physician and histologist in Paris.

Nodes of myelinated nerves (p. 17).

RATHKE Martin Heinrich (1793–1860) Professor of Zoology and Anatomy in Königsberg.

Ectodermal pharyngeal pouch forming the adenohypophysis (p. 569).

REISSNER Ernst (1824–1878) Professor of Anatomy in Dorpat and, later, Breslau.

Vestibular membrane of the cochlea (p. 534).

RETZIUS Andreas Adolf (1796–1860) Professor of Anatomy and Physiology in the Carolinska Institute, Stockholm, from 1840 to 1860.

Retropubic space (p. 394).

REXED Bror Anders (contemporary) Swedish physician and neuroscientist.

Laminae of the spinal cord (p. 622).

RINNE Friedrich Heinrich Adolf (1819–1868) Otologist in Göttingen.

Tuning-fork hearing test (p. 641).

ROLANDO Luigi (1773–1831) First Professor of Practical Medicine at Sassari (Sardinia) and, later, Professor of Anatomy at Turin.

Central sulcus of the cerebral hemisphere (p. 578).

ROMBERG Moritz Heinrich von (1795–1873) Professor of Medicine in Berlin and a famous neurologist.

Sign recognizing loss of posterior column sensibility (p. 623).

ROSENMULLER Johann Christian (1771–1820) Professor of Anatomy and Surgery in Leipzig from 1802 to 1820.

Pharyngeal recess (p. 490).

SANTORINI Giovanni Domenico (1681–1737) Professor of Anatomy and Medicine in Venice, and published a textbook of Anatomy.

Accessory pancreatic duct (p. 353).

SCARPA Antonio (1747–1832) Professor of Anatomy in Pavia. FRS 1791.

Fibrous layer of superficial fascia of the abdomen (p. 241).

SCHLEMM Friedrich (1795–1858) Professor of Anatomy in Berlin from 1833 to 1858.

Canal at the junction of the cornea and the sclera (p. 517).

SCHWANN Theodor (1810–1882) Professor of Comparative Anatomy and Physiology in Liege.

Neurilemmal cells of peripheral nerves (p. 17).

SHARPEY William (1802–1880) Professor of Anatomy in Edinburgh and, later, at University College, London, from 1836 to 1874 in succession to Jones Quain.

Connective tissue fibres between periosteum and bone (p. 8).

SHERINGTON Sir Charles Scott (1857–1952) Professor of Physiology in Liverpool from 1895 to 1913 and in Oxford from 1913 to 1936. FRS 1893.

Dermatomes (p. 24).

SHRAPNELL Henry Jones (1761–1834) Surgeon to S. Gloucestershire Regiment; married Edward Jenner's ward and became a surgeon and anatomist in London.

Pars flaccida of the tympanic membrane (p. 527).

SIBSON Francis (1814–1876) Professor of Medicine at St Mary's Hospital, London. Died while on holiday in Geneva.

Fascia or suprapleural membrane at the apex of the lung (p. 248).

SKENE Alexander John Chalmers (1838–1900) Born in Aberdeen, he studied in America and became Professor of Gynaecology in the Long Island College Hospital, Brooklyn and, later, at the New York Postgraduate Medical School.

Paraurethral glands of the female (p. 393).

STENSEN Niels (Nicolaus Steno) (1638–1686) Professor of Anatomy in Copenhagen. A pioneer in geology and crystallography, he gave up science to become a priest.

Parotid duct (p. 456).

STRUTHERS Sir John (1823–1899) Professor of Anatomy in Aberdeen from 1863 to 1889.

Fibrous band of the supratrochlear spur of the humerus (p. 79).

STURGE William Allen (1850–1919) and **WEBER Frederick Parkes** (1863–1962) London physicians.

Syndrome including portwine naevus in the trigeminal area (p. 450).

SYLVIUS François de la Boe (1614–1672) Professor of Practical Medicine in Leyden.

Lateral sulcus of the cerebral hemisphere (p. 578) and the aqueduct of the midbrain (p. 606).

TENON Jacques Rene (1724–1816) Professor of Pathology in the Academy of Sciences Paris and Chief Surgeon at the Salpêtrière.

Fascial sheath of the eyeball (p. 511).

TODARO Francesco (1839–1918) Professor of Anatomy in Messina and Rome.

Tendinous boundary of Koch's triangle in the heart (p. 272).

TREITZ Wenzel (1819–1872) Professor of Pathological Anatomy in Krakow and, later, Professor of Pathology in Prague.

Suspensory muscle of the duodenum (p. 335).

TRENDELENBURG Friedrich (1844–1924) Professor of Surgery at Rostock, Bonn and Leipzig.

Test for adductors of the hip (p. 164).

TREVES Sir Frederick (1853–1923) Surgeon to the London Hospital. With Lord Lister, operated on King Edward VII for appendicitis.

Ileocaecal fold of peritoneum (p. 339).

TROISIER Charles Emile (1844–1919) Professor of Pathology in Paris.

Sign of enlarged supraclavicular lymph nodes in gastric carcinoma (p. 334).

VATER Abraham (1684–1751) Professor of Anatomy, Botany, Pathology and Therapeutics in Wittenberg.

Hepatopancreatic ampulla in the duodenal wall (p. 335).

VESALIUS Andreas (1514–1564) Professor of Anatomy at Padua and, later, Bologna and Pisa. Physician to Charles V and Philip II of Spain. His anatomical atlas *De humani corporis fabrica* (Basle 1543) is one of the world's greatest books.

Venous foramen medial to the foramen ovale (p. 651).

VIDUS VIDIUS (Guido Guidi) (1500–1569) Physician to Francis I of France and from 1548 Professor of Medicine at the University of Pisa.

Nerve of the pterygoid canal (p. 468).

VOLKMANN Alfred Wilhelm (1800–1877) Professor of Physiology and Anatomy in Dorpat and, later, Halle.

Vascular canals in bone (p. 8).

WALDEYER Heinrich Wilhelm Gottfried (1836–1921) Professor of Pathological Anatomy in Breslau and, later, Berlin.

Fascia between the rectum and sacrum (p. 379), and ring of lymphoid tissue in the mouth and pharynx (p. 490).

WEBER Ernst Heinrich (1795–1878) Professor of Anatomy and Physiology in Leipzig.

Turning-fork hearing test (also attributed to Friedrich Eugen Weber, 1832–1891, German otologist) (p. 641).

WERNICKE Karl (1848–1904) Professor of Neurology and Psychiatry in Breslau and, later, in Halle.

Posterior speech area of the cerebral cortex (p. 586).

WHARTON Thomas (1616–1673) Physician to St. Thomas's Hospital, London.

Submandibular duct (p. 436).

WHITNALL Samuel Ernest (1876–1950) Professor of Anatomy at McGill University, Montreal (1919–1934) and at Bristol (1935–1941).

Marginal tubercle on the zygomatic bone (p. 506).

WILLIS Thomas (1621–1675) Physician to James II and one of the founders of the Royal Society.

Arterial circle at the base of the brain (p. 599).

WINSLOW Jacob Benignus (1669–1760) At the age of 74 was appointed Professor of Anatomy, Physic and Surgery in Paris and, until his death, was considered one of the best anatomical teachers in Europe.

Epiploic foramen (p. 315).

WIRSUNG Johann Georg (1600–1643) Professor of Anatomy in Padua, where he was assassinated.

Pancreatic duct (p. 353).

WOLFF Kaspar Friedrich (1733–1794) Professor of Anatomy and Physiology at St Petersburg. One of the founders of modern embryology.

Mesonephric duct (p. 309).

WORM Ole (1588–1654) Danish theologian and anatomist. Professor of Greek and Philosophy, and later became Professor of Anatomy in Copenhagen.

Sutural bones of the skull (p. 644).

WRISBERG Heinrich August (1739–1808) Anatomist and gynaecologist. Professor of Anatomy in Göttingen.

Anterior meniscofemoral ligament (p. 182).

Glossary

The derivation of words is interesting and informative. Here is a list of some common anatomical words with their derivations. It is meant for those who do not know Latin or Greek. Note that a Latin adjective should follow its noun and *must* agree in gender, case and number. Language and spelling change with time and usage and even mediaeval Latin, the language of European scholars, changed somewhat over the years from the ancient classical tongue. There is a modern tendency to simplify spelling, and more than one form of a word may now be considered acceptable.

Note some commonly mistaken plurals:

Singular noun	Plural noun
criterion Gr.	criteria
datum L.	data
foramen L.	foramina
medium L.	media
os L. a mouth	ora
os L. a bone	ossa
phenomenon Gr.	phenomena
retinaculum L.	retinacula

Abbreviations: Gr. is ancient Greek, L. is Latin

A

a- (**an-** before a vowel) prefix Gr. not, without (equiv. English *un-*)
ab- prefix L. from, away (e.g. abduct, lead from, the midline understood)
abdomen L. derivation uncertain (perhaps *abdere* to hide?)
abducent L. *ab-* from + *ducens* leading, from *ducere* to lead
aberrant L. deviating from normal, *ab-* from + *errare* to wander
acetabulum L. vinegar cup, *acetum* vinegar
achalasia Gr. *a-* not + *chhalasis* a slackening (i.e. failure to relax)
acinus L. a grape
acoustic Gr. *akoustikos* related to hearing
acromion Gr. *akros* extreme + *omos* shoulder (i.e. tip of shoulder)
ad- prefix L. to, towards (e.g. adduct, lead towards, the midline understood)

adenoid Gr. *aden* a gland + *-oid* like
adipose L. fatty, from *adeps* fat
aditus L. an opening or entrance, from *ad-* + *iter* a way
adrenal L. *ad-* + *ren* the kidney
afferent L. *ad* + *ferens* carrying, from *ferre* to carry
ala L. a wing
alaeque L. *alae* of the nose + *-que* suffix meaning 'and'
alba L. *albus* white
albicans L. becoming white
albuginea L. white, like the white of the eye, *albugo* white spot
-algia suffix Gr. *algos* pain
allantois Gr. *allantos* sausage + *-oid* like
alveolus L. diminutive of *alveus* a hollow
alveus L. a trough, a hollow (doubtful derivation on hippocampus)
ambi- prefix L. on both sides
ambiguus L. uncertain, equivocal
ameloblast old French *amel* enamel + Gr. *blastos* germ
amnion Gr. diminutive of *amnos* a lamb
ampulla L. a globular flask
amygdaloid Gr. *amygdalon* an almond + *-oid* like
amylacea Gr. starchy, from *amylon* starch
ana- prefix Gr. up, towards, apart (do not confuse with *an-* negative before a vowel)
anaesthesia Gr. *an-* not + *aisthesis* feeling, sensation
analogous Gr. *ana-* + *logos* word, meaning similar function though different structure such as fish gills and mammal lungs (cf. homologous)
anastomosis Gr. *ana-* towards + *stoma* a mouth (i.e. mouth to mouth)
anatomy Gr. *ana-* part + *tome* a cutting
anconeus Gr. *ankon* elbow
angina Gr. *anchone* choking distress
annulus L. ring (more accurate **anulus**)
ansa L. a handle, a loop
anserinus, anserina L. *anser* a goose
ante- prefix L. before, in space or time
anti- prefix Gr. against, counter, opposite
antrum L. from Gr. *antron* a cave
anus L. doubtful origin, possibly Anglo-Saxon to sit
aorta Gr. *aorte* to lift, to heave
aponeurosis Gr. *apo-* derived from + *neuron* a sinew
appendage L. from *appendere* to hang upon, like a tail
appendix L. same as appendage
apposition L. *oppositus* placed at (in contact)
aqueduct L. *aqua* water + *duct*, from *ducere* to lead
arachnoid Gr. *arachne* spider, spider's web + *-oid* like
archaocerebellum Gr. *archaios* ancient, primitive + *cerebellum* (q.v.)

archaeopallium Gr. *archaios* ancient + *pallium* a cloak, a mantle (of cortex)
arcuate L. *arcuatus* arched
arcus L. a bow, an arch
areola L. a zone, or a minute space, diminutive of *area*
areolar L. containing minute spaces
arrector L. that which raises, a raiser
artery Gr. *aer* air + *terein* to keep (arteries were thought to contain air)
articulation L. *articulatio* a forming of joints between sounds, bones etc.
-ary suffix, pertaining to (e.g. salivary)
arytenoid Gr. *arytaina* a ladle + *-oid* like
asterion Gr. *asterios* starry
ataxia Gr. *a-* no + *taxis* order
atlas Gr. mythology, a god who bears up the pillars of heaven
-atory suffix, causing (e.g. salivatory, causing salivation)
atresia Gr. *a-* without + *tresis* a hole
atrium L. from Gr. *atrion* a hall, the principal room in a house
auditory L. *audire* to hear
auricle L. diminutive of *auris* an ear
auscultation L. *auscultare* to listen to
autonomic Gr. independent, from *auto* self + *nomos* law
avis L. a bird, of a bird
axilla L. armpit
axon Gr. axis
azygos Gr. unpaired, from *a-* not + *zygon* yoke, pair (cf. L. *impar*)

B

basilic Gr. *basilikos* royal, important, prominent
biceps L. *bi-* two + *caput* head
bifurcate L. *bi-* two + *furca* a fork
blast Gr. *blastos* a germ
blastocyst Gr. *blastos* germ + *kystis* bladder
brachium L. from Gr. *brachion* arm
branchial Gr. *branchia* gills
bregma Gr. the front of the skull
brevi L. short, brief
bronchus Gr. *bronchos* the windpipe
buccal L. *bucca* the cheek
buccinator L. a trumpeter
bulbi L. genitive of *bulbus* a bulb, a rounded mass (e.g. eyeball)
bull L. a bleb, a large vesicle
bursa L. a purse

C

caecum L. blind
caeruleus L. sky-blue
calcaneus L. heel
calcar L. a spur
calcarine L. spur-shaped
callosus L. *callus* thick skin, a callus
calyx Gr. *kalyx* a bud, Gr. *kylix* a cup
canaliculus L. diminutive of *canalis* a canal
canine L. *caninus*, from *canis* a dog
canthus Gr. *kanthos* the corner of the eye, a niche
capitate L. *capitatus* head-like
capitis L. genitive of *caput* the head

capitulum L. diminutive of *caput* the head
caput medusae L. *caput* head *medusae* of Medusa Gr. myth. female with snaky hair
cardiac L. from Gr. *kardia* the heart
cardinal L. *cardinalis* principal
carina L. a keel
carneae L. *carneus* fleshy, from *caro*, *carnis* flesh
carnosus L. fleshy
carotid Gr. *karos* heavy sleep. The Greeks thought the carotid arteries caused drowsiness
carpus L. from Gr. *karpus* the wrist
cartilage L. *cartilago* gristle (Gr. is *chondros*)
caruncle L. a small fleshy mass from *caro* flesh
catheter Gr. a thing sent down or put in, from *kata* down + *hienai* to send
cauda L. a tail **equina** L. adjective of *equus* a horse
caudate L. from *cauda* a tail
cava L. *cavus* hollow
cavernosus L. *cavernosus* containing hollow spaces, cavernous
celiac, coeliac L. from Gr. *koiliakos*, from *koilia* belly
celom, coelom Gr. *koiloma* a hollow, from *koilos* hollow
centrum L. from Gr. *kentron* centre
cephalic Gr. *kephale* head
cerebellum L. diminutive of *cerebrum* the brain
cerebrum L. the brain
ceruminous L. *cerumen*, *cera* wax
cervix L. neck
chiasma Gr. two crossed lines, from the letter chi (X)
choana L. from Gr. *choane* a funnel
chondro- Gr. *chondros* cartilage, gristle, coarse-ground grain
chorda Gr. *chorde* a cord
choroid (more accurate **chorioid**) Gr. *chorion* a vascular membrane + *-oid* like
chromaffin Gr. *chroma* colour + *affinis* affinity
chromatin Gr. *chroma* colour
chyl L. genitive of *chylus* juice
ciliary L. from *cilia* eyelashes, from *cilium* eyelid
ciliated provided with cilia
cinereum L. *cinereus* ash-coloured
cingulum L. a girdle
circumflex L. *circum* around + *flexus* a bending
cisterna L. a cistern, a tank, a reservoir
-clast Gr. *klastos* broken, *klastis* a breaker
claustrum L. a barrier
clavicle L. a little key, *clavis* a key (Gr. *kleidos* as in sternocleidomastoid)
clinoid Gr. *kline* a bed + *-oid* like (cf. clinical)
clitoris Gr. *kleitoris* from *klein* to shut up
clivus L. a slope, a hill
cloaca L. a drain, a sewer
coccyx Gr. *kokkyx* the cuckoo, whose beak the bone resembles
cochlea L. snail, snail-shell
coli L. of the colon
collateral L. subsidiary, not in the main stream, from *con-* together + *latus* side
colli L. genitive of *collum* the neck
colliculus L. a little hill, a mound
colon L. from Gr. *kolon* the largest of the intestines
comitans L. *comes* a companion
commissure L. a joining together, from *con-* together + *mittere* to send
concha L. from Gr. *konche* a shell
condyle L. from Gr. *kondylos* a joint, a fist, a knuckle

congenital L. *con-* with + *genitus* begotten
conjunctiva L. connective, from *con* with + *jungere* to join, to bind
conoid Gr. *konoeides* resembling a cone
coracoid Gr. *korax* a crow + *-oid* like
corium L. skin, hide, leather
cornea L. *corneus* horny, from *cornu* a horn
corniculate L. shaped like a small horn
cornu L. a horn
corona L. from Gr. *korone* a crown
coronary encircling like a crown
coronoid Gr. like a crown, from *korone* a crown + *-oid* like
corpus L. a body
corpuscle L. diminutive of *corpus*
corrugator L. *corrugare* to wrinkle, from *ruga* a wrinkle
cortex L. bark, shell
costa L. a rib
cranium L. from Gr. *kranion* the upper part of the head
cremaster L. from Gr. *kremaster* from *kremannymi* to hang, to suspend
cribriform L. *cribrum* a sieve + *forma* shape, form
cribrosa L. *cribrose*, same as *cribriform*
cricoid Gr. *krikos* a ring + *-oid* like
crista L. a crest, a ridge
cruciate L. crossed, from *crux* a cross
cruciform L. shaped as a cross, from *crux* a cross + *forma* shape
crus L. the leg between knee and ankle
crypt Gr. *kryptos* hidden
cubital L. *cubitum* elbow
cuboid Gr. *kyboeides* resembling a cube
cumulus L. a little mound, a heap
cuneate L. *cuneus* a wedge
cuneiform L. wedge-shaped, same as *cuneate*, from *cuneus* wedge + *forma* shape
cupola L. a little tub, a little dome
cusp L. *cusps* a pointed tip
cutaneous L. *cutis* skin
cyst L. from Gr. *kystis* a sac, a bladder
-cyte, cyto-, cyt- Gr. *kytos* a hollow vessel (used to denote a cell)

D

dartos Gr. flayed, skinned
decussation L. *decussatio* a crossing like the letter X (cf. Gr. *chiasma*)
deferens L. carrying away, from *de-* away + *ferens* carrying, from *ferre* to bear, to carry
deglutition L. swallowing, from *de-* down, away + *glutire* to swallow
dehiscence L. a separation, from *dehiscere* to gape
deltoid Gr. delta, fourth letter in alphabet (Δ), triangular + *-oid* like
dendrite Gr. of a tree, from *dendron* a tree
dens L. a tooth
dentate L. having tooth-like projections
denticulate L. having tiny tooth-like projections
dentine L. from *dens* a tooth
dentition L. *dentitio* from *dentire* to cut teeth
dermatome Gr. *derma* the skin + *tome* a cutting, from *temnein* to cut
dermis Gr. *derma* hide, skin
detrusor L. *de-* from, down + *trudere* to thrust, to push

di- Gr. *dis* twice, double
dia- Gr. through
diaphragm Gr. *dia-* through + *phragnum* to fence (i.e. a partition)
diastole Gr. *dia-* through + *stellein* to set, to place (i.e. to separate)
diencephalon Gr. *dia-* through + *enkephalon* brain
digastric Gr. *di-* double + *gaster* belly, stomach
digit L. a finger or a toe
diploë Gr. *diploe* a fold, from *diploos* twofold, double
diplopia Gr. *diploos* double + *ope* sight
discus L. from Gr. *diskos* a disc
diverticulum L. a by-road, from *de-* aside + *vertere* to turn
dorsum L. the back
duct L. *ductus* from *ducere* to lead, to draw
duodenum L. *duodeni* twelve each (its approximate length in finger breadths)
dura mater L. *dura* hard, tough + *mater* mother
dysdiadochokinesia Gr. ill performance of rapidly alternating movements, from *dys-* ill, difficult + *diadochos* successive + *kinesis* movement
dysphagia Gr. *dys-* difficult + *phagein* to eat
dysphonia Gr. *dys-* difficult + *phono* voice

E

ecto- prefix Gr. *ektos* outside (cf. L. *ex*)
ectoderm Gr. *ektos* outside + *derma* skin
ectopia Gr. *ek* out + *topos* place
effluent L. *ex* out + *ferens* carrying, from *ferre* to carry
ejaculatory L. *ex* out + *jacere* to throw
emboliformis Gr. *embolos* a plug, a stopper + L. *forma* shape
embryo Gr. *en* in + *bryein* to swell, to teem
emissary L. providing an outlet, from *ex* out + *mittere* to send
encephalon Gr. *enkephalos* brain, from *en* in + *kephale* head
endo- prefix Gr. *endon* within (L. *intra-*)
endocrine Gr. *endo* inside + *krinein* to separate, to secrete
endoderm Gr. *endo* inside + *derma* skin
endolymph Gr. the water inside, from *endo* + *lymph* water
endothelium Gr. *endo* inside + *thelē* the nipple(!)
ependyma Gr. *ependyma* an upper garment
epi- prefix Gr. *epi-* upon
epidermis Gr. *epi-* upon + *derma* skin
epididymis Gr. *epi-* upon + *didymos* testicle (lit. twins)
epiglottis Gr. *epi-* upon + *glotta, glossa* tongue
epimysium Gr. *epi-* upon + *mys* muscle
epiphora Gr. *epi-* upon + *pherein* to bring
epiphysis Gr. *epi-* upon + *physis* growth, from *phyein* to grow
epiploic Gr. *epiploon* omentum, from *epi-* upon + *ploon* floating
epithelium Gr. *epi-* upon + *thelē* the nipple(!)
epoöphoron Gr. *epi-* upon + *oöphoron* ovary, from *oon* egg + *pherein* to carry
erigentes L. plural, erecting, from *erigere* to erect
eruption L. *ex* out of + *rumpere* to break
erythrocyte Gr. *erythros* red + *kytos* cell
ethmoid Gr. *ethmos* a sieve + *-oid* like
eversion L. *ex* out + *vertere* to turn
evolution L. *ex* out + *volvare* to roll, i.e. to unroll
extra- prefix L. *extra-* beyond, outside of (opposite to *intra-*)

F

- fabella** L. diminutive of *faba* a bean
falciform L. *falx* a sickle + *forma* shape
falx L. a sickle
fascia L. a band, a sash, a bandage
fasciculus L. a small bundle, diminutive of *fascis* a bundle
fastigii L. genitive of *fastigium* a gable end
fauces L. plural of *faux* a narrow passage, a gorge
femur L. *femur* the thigh
fenestra L. a window
ferruginea L. *ferrugo* iron rust, from *ferrum* iron
fetus, foetus L. a bringing forth, brood, offspring, young one
fibula L. a buckle (Gr. was *perone*)
filum L. a thread
fimbria L. a fringe
fissure L. *fissura* a cleft, a groove
fistula L. a pipe, a tube
flavus, flava, flavum L. yellow
flexion L. the act of bending, from *flectere* to bend
flexure L. a bend in a structure, from *flectere* to bend
flocculus L. diminutive of *floccus* a flock, a tuft of wool
folia L. plural of *folium* a leaf
follicle L. diminutive of *folliculus* bellows, inflated leather ball, money bag
fontanelle French diminutive of *fontaine* a fountain
foramen L. a small opening, from *forare* to bore, to pierce
forceps L. pincers, tongs, from *formus* hot + *capere* to take
-form suffix L. *forma* shape (Gr. *eidos*, hence suffix *-oid*)
foramen L. a vault, an arch, a brothel
fossa L. a ditch, from *fodere* to dig
fovea L. a small pit
frenulum L. diminutive of *frenum* a bridle
frondiform L. *frons* a leafy branch, a frond + *forma* shape
frontal L. *frons* the front, the fore part
fundus L. bottom of a cavity, the part furthest from the opening
fungiform L. *fungus* mushroom + *forma* shape
furcula L. diminutive of *furca* a fork (especially the wishbone)
fusiform L. *fusus* a spindle + *forma* shape
fusion L. *fusio* melting, blending as if liquefied, from *fundere*, *fusum* to pour

G

- galea** L. a helmet
galli L. genitive of *gallus* a cock
ganglion Gr. a knot, a swelling
gastric Gr. *gaster* stomach
gastro- prefix Gr. from *gaster* stomach
gastrocnemius Gr. *gastro-* + *kneme* leg
gelatinosa L. *gelatus* frozen
gemellus L. a twin
-gen suffix Gr. from *gennan* to produce
geniculum L. diminutive of *genu* a knee
genio- Gr. *geneion* chin
genitalia L. reproductive organs, from *genitalis* belonging to birth
genu L. the knee
germinativum L. *germen* a sprout, a bud, a germ
gingival L. *gingiva* the gum
gladiolus L. diminutive of *gladius* a sword

- glans** L. an acorn
glenoid Gr. *glene* socket + *-oid* like
-glia Gr. *glia* glue
globosus L. from *globus*
globus L. a ball, a globe, a sphere
glomerulus L. diminutive of *glomus* a ball
glomus L. a ball (of thread)
glossus Gr. *glossa* tongue
glottis Gr. the vocal apparatus, from *glotta* tongue
gluteus L. from Gr. *gloutos* rump, buttock
glycogen Gr. *glykys* sweet + *gennan* to produce
goitre L. *guttur* throat
gonad Gr. *gone* that which generates, seed
gracile, gracilis L. *gracilis* slender
granulosum L. *granulum* a small grain
-graphy suffix Gr. *graphein* to write
griseum L. *griseus* grey
gubernaculum L. rudder, from *gubernare* to steer
gustatory L. *gustatio* taste
gyrus L. from Gr. *gyros* a ring, a circle

H

- habenula** L. diminutive of *habena* a strap
haemopoiesis Gr. *haima* blood + *poiesis* making
haemorrhoid Gr. *haimorrhoid* a vein that bleeds, from *haima* blood + *rhoia* a flow
hallux L. *hallex* the great toe
hamate L. hooked, from *hamus* a hook
hamulus L. diminutive of *hamus* a hook, i.e. a little hook
haustrium L. a machine for drawing water
helicine Gr. *helix* a snail, a coil
helicotrema Gr. *helix* a spiral + *trema* a slit, a hole
hemiplegia Gr. *hemi-* half + *plegia* stroke
hepatic Gr. *hepar* the liver
hernia L. protrusion through an opening
herpes L. from Gr. *herpein* to creep
hetero- Gr. other, different, from *heteros* other
hiatus L. *hiare*, *hiatum*, to gape, to yawn
hippocampus Gr. a sea horse, from *hippos* a horse + *kampos* a sea monster
histiocyte Gr. *histos* web, tissue + *kytos* cell
histology Gr. *histos* web (tissue) + *logos* discourse
hilum L. a small bit, a trifle
homo L. a man
homo- Gr. *homos* the same
homologous Gr. *homo* + *logos* word, meaning similar structure, corresponding, such as muscles and nerves etc. in upper and lower limbs (cf. analogous)
hormone Gr. *hormaein* to excite
humerus L. *umerus* shoulder (Gr. *omos*)
humour L. *umor* liquid
hyaline Gr. glassy, from *hyalos* glass
hyaloid Gr. *hyalos* glass + *-oid* like
hydro- Gr. *hydor* water
hymen Gr. membrane
hyoid Gr. letter upsilon (*ú*) + *-oid* (i.e. U-shaped)
hyper- prefix Gr. above, over (same as L. *supra-*)
hypo- prefix Gr. under (same as L. *sub-*)
hypochordal Gr. *hypo-* under + *chorde* cord, meaning notochord
hypophysis Gr. an undergrowth, from *hypo-* under + *physis* growth, from *phyein* to grow
hypotheneal Gr. *hypo-* under + *thenar* palm of the hand

I

- ileum** L. distal small intestine, from Gr. *eilein* to twist, to roll up
iliac L. *ilia* loins
ilium L. loin, flank
ima L. lowest
impar L. unequal, unpaired (cf. Gr. *azygos*)
incisor L. a cutting tooth, from *in* into + *coedere* to cut
incisura L. a cut, an incision, a notch
incus L. an anvil
index the forefinger, from *indicare* to point out
indicus L. genitive of index
indusium L. an undergarment, *induere* to put on (a garment)
infarct L. *in*-in + *farcire*, *farcium* to stuff, to cram
infra- prefix L. beneath (cf. *sub-* L. under and *hypo-* Gr. under)
infundibulum L. a funnel, from *infundere* to pour in
inguinal L. *inguen* the groin
innominate L. unnamed, from *in-* not + *nomen* name
insula L. an island
inter- prefix L. between
internuncial L. *inter-* + *nuncius* a messenger
intimus L. inmost, deepest
intra- prefix L. within (opposite to *extra-*)
introitus L. *intro-* within + *ire* to go
inversion L. *in-* in + *vertere* to turn
iris L. from Gr. the rainbow
ischium L. from Gr. *ischion* the hip
-itis suffix Gr. denoting inflammation

J

- jejunum** L. empty, hungry
jugular L. *jugulum* the neck, the throat, the collar bone
jugum L. a yoke, a ridge
juxtaglomerular L. *juxta-* adjoining + *glomerulus* (q.v.)

K

- keratin** Gr. *keras* horn

L

- labium** L. a lip
labrum L. a lip
labyrinth L. from Gr. *labyrinthos* a maze
lacerum L. a jagged wound, from *lacerare* to tear, to lacerate
lacrima L. a teardrop (Gr. *dakrya*)
lactation L. *lac*, *lactis* milk, any white liquid
lacteal L. resembling milk (e.g. a lacteal vessel)
lacuna L. a pit, a lake, a hollow
lacus L. a lake
lambda Gr. letter in alphabet (λ)
lamella L. diminutive of *lamina*
lamina L. a plate, a layer
lanugo L. *lana* wool
larynx Gr. upper part of windpipe
lata L. *latus* wide
lateral L. *lateris* side, flank
latissimus L. widest, from *latus* wide
lemniscus L. from Gr. *lemniskos* a ribbon hanging down
lentiform L. *lens* a lentil + *forma* shape
leucocyte Gr. *leukos* white + *kytos* cell

- levator** L. a lifter, an elevator
lienal, lieno- L. *lien* the spleen
limbic L. *limbus* a border, a fringe
limitans L. limiting, from *limes* boundary
lingua L. the tongue
lingula L. little tongue, diminutive of *lingua* tongue
locus L. a place
-logy Gr. *logos* the word, discourse
longissimus L. longest
longus L. long
lucidum L. *lucidus* clear
lumbar L. *lumbus* loin
lumbrical L. *lumbricus* earthworm
lunate L. *lunatus* crescent-shaped, from *luna* the moon
lutea L. *luteus* yellow
lymph L. *lymph* clear water

M

- macro-** Gr. *makros* large
macula L. a spot, a stain, a blemish
magna L. *magnus*, *magna*, *magnus* great
malleolus L. a little hammer, from *malleus* a hammer
malleus L. a hammer
mamillaria L. *mamilla* a nipple
mamma L. a breast, a teat
mandible L. *mandibula* lower jaw, from *mandere* to chew
manubrium L. handle, from *manus* a hand
manus L. the hand
masseter L. from Gr. *maseter* chewer
mastication L. *masticare* to chew
mastoid Gr. *mastos* breast + *-oid* like
matrix L. womb, or a female breeding animal
maxilla L. a jawbone, either upper or lower
maximus, maxima, maximum L. biggest
meatus L. a passage, from *meare* to go
medial L. from *medius* middle, i.e. towards the midline
median L. *medianus* in the midline
mediastinum L. a median partition
medius L. middle
medulla L. marrow, pith
meiosis Gr. a lessening
melanin Gr. *melas* black
meninges Gr. plural of *meninx* membrane
meniscus L. from Gr. *meniskos* a crescent, diminutive of *mene* the moon
mental L. *mentum* the chin (*mens* L. the mind)
meralgia Gr. *meros* thigh + *algos* pain
mesenchyme Gr. *mesos* middle + *chymos* juice
mesentery Gr. *mesos* middle + *enteron* intestine
meso- prefix Gr. from *mesos* middle
meta- prefix Gr. between, with, after (e.g. *metacarpus*, *metanephros* etc.), like L. post-
metanephrogenic Gr. *meta-* after + *nephros* kidney + *gen* producing
metopic Gr. *metopon* the forehead
micro- Gr. *mikros* small
micturition L. *micturare* to desire to pass urine
minimus, -a, -um L. smallest
mitosis Gr. *mitos* thread
modiolus L. a nave, a hub
molar L. *molaris* from *mola* a mill for grinding
morphology Gr. *morphe* form + *logos* discourse
morula L. diminutive of *morus* a mulberry

motor L. a mover, from *movere* to move
multifidus L. multi- many + *findere* to split
myelo- Gr. *myelos* marrow
myenteric Gr. *mys* muscle + *enteron* intestine
mylo- Gr. from *myle* a mill and *mylai* lower teeth (refers to lower jaw)
myo- Gr. *mys* a muscle
myotome Gr. *mys* muscle + *tome* a piece cut off, from *temnein* to cut

N

nares L. plural of *naris* a nostril
navicular L. *navicula* a boat, diminutive of *navis* a ship (Gr. scaphoid)
neo- prefix Gr. *neos* new
neonatus L. from Gr. *neo-* new + *natus* born
neopallium Gr. *neo-* new + *pallium* a mantle, a cloak (of cortex)
nephron Gr. *nephros* kidney
neurilemma Gr. *neuron* nerve + *lemma* a husk
neurobiotaxis Gr. *neuron* nerve + *bios* life + *taxis* arrangement
neuroglia Gr. *neuron* nerve + *glia* glue
neuron Gr. a nerve, a sinew (no distinction until Galen's time)
nigra L. *niger* black
node L. *nodus* knot
nodule L. *nodulus* a little knot, diminutive of *nodus* a knot
notochord Gr. *noton* back + *chorde* cord
nuchae L. genitive of *nucha* the nape, the back of the neck
nucleus L. a kernel, diminutive of *nux* a nut
nystagmus Gr. *nystagmos* nodding, from *nystazein* to be sleepy, to nod

O

obturator L. that which stops an opening, from *obturare* to stop up, to plug
occiput L. *ob* back + *caput* head
oculomotor L. *oculus* eye + *motor* mover
oculus L. an eye (Gr. *ophthalmos*)
odontoblast Gr. *odous* tooth + *blastos* germ
oedema Gr. *oidema* swelling, from *odein* to swell
oesophagus Gr. *oisein* to carry + *phagema* food, from *phagein* to eat (cf. phagocyte)
-oid suffix Gr. like, resembling, in the form of, from *eidōs* form, shape
olecranon Gr. *olene* elbow + *kranion* the head
olfaction L. *olfacere* to smell, from *odere* to have a smell + *facere* to make
omentum L. fatty membrane, from *induere* to put on, to clothe
omo- Gr. *omos* shoulder
ontogeny Gr. *ontos*, existing, an individual + *genman* to produce
oocyte Gr. *oon* an egg, + *kytos* a hollow vessel, a cell
operculum L. a cover, a lid
ophthalmic Gr. *ophthalmos* an eye (L. *oculus*)
ophthalmoscope Gr. *ophthalmos* eye + *skopein* to examine, to view
opponens L. placing against, opposing
optic L. *opticus* from Gr. *optikos* of sight, for sight
ora L. an edge, a margin
oral L. *os, oris*, a mouth

orbicular L. *orbicularis* circular, rounded, from *orbis* a circle
orbit L. *orbita* a wheel track, a circuit
os, oris L. a mouth, an opening (plural *ora*)
os, ossis L. a bone (plural *ossa*)
-osis suffix Gr. condition, state, process
ossification L. *os* bone + *facere* to make
osteoblast Gr. *osteon* bone + *blastos* germ
osteoclast Gr. *osteon* bone + *klastis* a breaker
osteocyte Gr. *osteon* bone + *kytos* hollow vessel, cell
osteology Gr. *osteon* bone + *logos* word, discourse
ostium L. a door, an opening
otic Gr. *otos* ear
otolith Gr. *otos* ear + *lithos* stone
otoscope Gr. *otos* ear + *skopein* to examine, to view
ovum L. an egg
oxyntic Gr. *oxys* sour, *oxynein* to make acid

P

paleo- prefix Gr. *palaio* old
palate L. *palatum* the palate
palpebra L. an eyelid
pampiniform L. *pampinus* a tendril + *forma* shape
pancreas Gr. *pan* all + *kreas* flesh
panniculus L. diminutive of *pannus* cloth
papilla L. nipple
para- prefix Gr. alongside, near
paradidymis Gr. *para-* alongside + *didymos* testicle (lit. twins)
paralysis Gr. *para-* alongside + *lyein* to loosen
paraplegia Gr. *para-* alongside + *plegia* stroke
parenchyma Gr. *para-* beside + *en* in + *chein* to pour (into the stroma q.v.)
parietal L. of the wall of a cavity, from *paries* a wall
paroöphoron Gr. *para-* alongside + *oophoron* ovary, from *oon* egg + *pherein* to bear
parotid Gr. *para-* near + *otos* ear
patella L. diminutive of *patena* a flat dish
pecten L. a comb
pectinate L. shaped like a comb, from *pecten* a comb
pectineal L. from *pecten pubis*, of the pubic bone
pectineus L. from the pecten of the pubic bone
pectiniform L. *pecten* a comb + *forma* shape
pectoral L. *pectus, pectoris* the breast
peduncle L. *pedunculus* a stalk, from *pes* foot
pellucidum L. translucent, from *per* through + *lucidus* clear
pelvis L. a basin
penis L. *penis* a tail (cf. appendage, appendix)
pennate L. *penna* a feather
peri- prefix Gr. around
perilymph Gr. the water around, from *peri-* around + *lymph* water
perineum Gr. *peri-* around + *ineo* discharge, evacuate
periodontal Gr. *peri-* around + *odous* tooth
peripheral Gr. *peri-* around + *pherein* to bear, to carry
peristalsis Gr. *peri-* around + *stalsis* constriction
peritoneum Gr. *peri-* around + *leinein* to stretch, to extend
peroneal Gr. *perone* a fibula, brooch
pes, pedis L. the foot
petrosal L. *petrosus* like a rock
petrous Gr. stony, from *petra* stone
phaeo- Gr. *phaios* grey, dusky
phagocyte Gr. *phagein* to eat + *kytos* cell
phalanx Gr. a line of soldiers

phallus Gr. *phallos* penis
pharynx Gr. throat
philtrum L. from *philtro* a love charm, from *philein* to love
phlebitis Gr. *phlebos* a vein + *itis* inflammation
phonation Gr. *phone* voice
photopic Gr. *phos*, *photos* light + *ope* sight
phrenic Gr. *phren* diaphragm, mind, heart as centre of emotions
phylogeny Gr. *phylon* tribe + *genesis* production, from *gennēin* to produce
pia mater L. *pia* soft, tender + *mater* mother
piles L. *pila* a ball; common name for haemorrhoids
pilomotor L. *pilus* a hair + *motor* mover
pineal L. *pine* a pine cone
piriform L. *pirum* a pear + *forma* shape
pituitary L. *pituita* mucus (the gland was thought to produce nasal mucus)
placenta L. a cake
placode Gr. *plax* something flat or broad + *-oid* like
plantar L. *planta* sole of foot
platysma Gr. *platys* broad
pleomorphic Gr. *pleion* more + *morphe* form
pleura Gr. a rib, the side
plexus L. a network, from *plexum* braid
plica L. a plait, a fold
pneumon Gr. *pneuma* air
pollex L. the thumb
pollicis L. of the thumb, genitive of *pollex*
poly- prefix Gr. *polys* many
polymorphonuclear Gr. *polys* many + *morphe* shape + L. *nucleus* little nut
pons L. a bridge
popliteus L. *poples* ham
porta L. an entrance, a portal
post- L. after (like Gr. *meta-*)
pre- prefix L. from *proe* before in space or time
prepuce L. *preputium* foreskin, from *pre-* before + *putium* uncertain derivation
pretrematic L. *pre-* before + *trema* a hole, a slit, a gill-cleft
primus, prima, primum L. first
princeps L. chief, from *primus* first + *capere* to take
procerus L. *pro-* instead of + *cerus* L. from Gr. *keros* horn
proctitis Gr. *proktos* anus + *itis* inflammation
proctodaeum Gr. *proktos* anus + *hodaio* on the way
profundus L. deep, from *pro-* before + *fundus* bottom
proligerus L. *proles* offspring + *gerere* to bear
prominens L. projecting
pronation L. *pronare* to bend forward, hence to face downward
pronephros Gr. *pro-* before, in front of + *nephros* kidney
proprioceptive L. *proprius* one's own + *capere* to take
prostate Gr. *prostata* one who stands before, from *pro-* before + *histana* to set
pseudo- Gr. *pseudes* false
psaos Gr. *psao* loin muscle
pteron Gr. *pteron* a wing
pterygoid Gr. *pterygos* wing + *-oid* like
ptosis Gr. a falling
pubis L. the bone, from *pubes* lower abdominal secondary sex hair
pubendal L. from *pubendum* external genitalia, from *pubere* to be ashamed
pulmonary L. *pulmo*, *pulmonis* a lung
pulposus L. pulpy, juicy
pulvinar L. a couch, a cushioned seat, a pillow

punctum L. a sharp point, from *pungere*, *punctus* to prick
pupil L. diminutive of *pupa* a doll (from image reflected in cornea)
putamen L. a shell, a piece snipped off in pruning
pyelogram Gr. *pyelos* a trough (pelvis) + *graphein* to write
pyknotic Gr. *pyknosis*, from *pyknos* dense + *-osis* state, condition
pylorus Gr. gatekeeper, from *pyle* gate + *ouros* guardian

Q

quadrangular L. *quadri-* four + *angulus* angle (L. *quattuor* four)
quadrate L. *quadratus* squared, four-sided
quadriceps L. *quadri-* four + *caput* head
quadrigenina L. *quadri-* four + *geminus* twin (born four together, fourfold)
quinti L. *quintus* fifth

R

radicular L. *radix* root
radius L. a spoke
ramus L. a branch
ranine L. *rana* a frog
raphe Gr. *rhaphe* a seam
receptaculum L. a reservoir, from *re-* back + *capere* to receive
rectus, recta, rectum L. straight, as if ruled
recurrent L. *re-* back + *currere* to run
renal L. *ren* the kidney
renule L. diminutive of *ren*, hence a small kidney
restiform L. *restis* rope + *forma* shape, form
rete L. a net
reticular L. *reticulum* diminutive of *rete*
retina L. from *rete* a net
retinaculum L. a rope, a band, a cable
retro- prefix L. backward, behind in position
rhinencephalon Gr. *rhis* nose + *enkephalos* brain
rhomboid Gr. *rhombus* a figure with four equal sides not right-angled + *-oid* like
rima L. a cleft, a fissure
risorius L. *ridere*, *risum* to laugh
rostrum L. beak
rotundum L. *rotundus* round
rubro- prefix L. from *rubrum* red
rugose L. wrinkled, from *ruga* a wrinkle

S

sacciform L. *saccus* a sack + *forma* shape
saccule L. *sacculus* a little sack, a little bag
sacrum L. *sacer* sacred
sagittal L. *sagitta* an arrow
salpinx Gr. a tube, a trumpet
saphenous Gr. *saphenes* manifest, apparent, not hidden (or Arabic *safin* standing?)
sartorius L. *sartor* a tailor (sitting cross-legged)
scala L. a staircase
scalene Gr. *skalenos* triangle with unequal sides
scaphoid Gr. *skaphe* a skiff, a small boat + *-oid* like (L. *navicular*)
scapula L. the shoulder blade
sciatic Gr. *ischiadikos*, of the *ischion* hip
sclera Gr. *skleros* hard

sclerotome Gr. *skleros* hard + *tome* a cutting, from *temnein* to cut

scoliosis Gr. *skolios* crooked, curving + *-osis* condition

scotopic Gr. *skotos* darkness + *ope* sight

scrotum L. a bag

sebaceous L. *sebum* tallow, grease + *aceus* pertaining to

sella turcica L. *sella* a seat, a saddle and *turcica* Turkish (a high-backed saddle)

semilunar L. *semi-* half + *luna* the moon

seminiferous L. *semen* seed + *ferre* to carry, to bear

serous L. like serum

serum L. clear liquid separated from a solid, like whey from curds

serratus L. toothed, from *serra* a saw

sesamoid Gr. *sesamon* sesame (seed) + *-oid* like

sigmoid Gr. *sigma* the letter S + *-oid* like

singulare L. *singulus* single, separate

sinus L. a fold, a curve, a hollow

soleus L. *solea* sole of the foot

solitarius L. solitary, alone, no companions

somatic Gr. *somatikos* of the body wall not viscera

somatopleure Gr. *somatos* body + *pleura* side

somite Gr. *soma* body

spermatocyte Gr. *sperma* seed + *kytos* cell

spermatogenesis Gr. *sperma* seed + *genesis* production

spermatogonium Gr. *sperma* seed + *gone* that which generates

spermatozoon Gr. *sperma* seed + *zoon* animal

sphenoid Gr. *sphen* a wedge + *-oid* like

sphincter Gr. *sphinkter* a tight binder, from *sphingein* to bind tight

spine L. *spina* a thorn, or the backbone

splanchnic Gr. *splanchnon* an entrail, an organ (L. *viscus*)

splanchnopleure Gr. *splanchnon* an organ + *pleura* side

spleen Gr. *splen* the spleen (L. *lien*)

splenium Gr. *splenion* bandage

splenius Gr. *splenion* a bandage

splenule L. from Gr. *splenulus* a little spleen

spondylolisthesis Gr. *spondylon* a vertebra + *olisthanein* to slip

spongiosum L. *spongiosus* spongy, porous

spurious L. *spurius* false, spurious

squamous L. *squama* a scale

stapedius L. of the stirrup

stapes L. a stirrup

stellate L. starry, from *stella* a star

stereocilia Gr. *stereos* solid + *cilia* (i.e. non-motile microvilli)

stereognosis Gr. *stereos* solid + *gnosis* knowledge (knowing shape by touch)

sternebra L. *sternum* + *vertebra* (q.v.)

sternum L. breast bone from Gr. *sternon* breast, chest

stoma Gr. a mouth

stomodaeum, stomodeum Gr. *stoma* mouth + *hodaio* on the way

stratum L. a layer

stria L. a furrow, a groove, a stripe

stroma Gr. *stroma* bed (used for 'framework', usually connective tissue)

styloid Gr. *stylos* a pillar + *-oid* like

sub- prefix L. under, below (Gr. *hypo-*)

subclavian L. *sub-* under + *clavis* a key = clavicle

subiculum L. diminutive of *subex* a support

sublimis L. superficial

sudomotor L. *sudor* sweat + *motor* mover

sulcus L. furrow, a groove

supination L. *supinatio* from *supinare* to bend backwards, face up

supra- prefix L. above, over; *super* L. above, beyond

suprarenal L. *supra-* over + *ren* the kidney

sural L. *sura* the calf of the leg

sustentaculum L. a support

suture L. *sutura* a seam

symphysis Gr. a growing together, from *syn* with + *phyein* to grow

synapse Gr. *syn* with + *haptein* to clasp

syncytium Gr. *syn* with + *kytos* cell

syndrome Gr. *syn* with + *dramein* to run

synergic Gr. *syn* with + *ergon* work

synovial Gr. *syn* with + *oon* egg (like white of egg)

syringomyelia Gr. *syringo* a pipe + *myelos* marrow

syrinx Gr. a pipe

systole Gr. *syn* with + *stellein* to set, to place (i.e. to contract)

T

tactile L. *tangere*, *tactus*, to touch

taenia Gr. *tainia* a band, a tape

talus L. ankle

tapetum L. from Gr. *tapete* a carpet, a tapestry

tarsus Gr. *tarsos* a flat surface, thus sole of foot and also eyelid edge

tectorial L. *tectorium* an overlaying surface, such as plaster

tectum L. a roof

tegmen L. a covering

tegumentum L. a covering, from *tegere* to cover (cf. *integument*)

tela L. a web

tele Gr. distant, afar (e.g. *telencephalon*)

temporal L. *tempus* time, thus *tempora* the temples (grey hair starts here)

tendon L. from Gr. *tenon* sinew, from *teinein* to stretch out, to extend

tentorium L. a tent

teres L. round and long

tertius L. the third

testicle L. diminutive of *testis*

testis L. a witness (of sex, hence the male gonad)

tetra Gr. four

tetralogy Gr. *tetra* four + *logos* discourse, a collection of four

thalamus Gr. *thalamos* an inner chamber, a bedroom

theca L. from Gr. *theke* a box, a case, a capsule

thenar Gr. palm of the hand

thorax L. from Gr. *thorax* breastplate, the chest, from *thoressein* to arm

thrombus Gr. *thrombos* a lump, a curd, a clot

thymus Gr. *thymos* sweetbread (resembling a bunch of thyme flowers)

thyroid Gr. *thyreos* a shield + *-oid* like

tibia L. a flute, a pipe

tonsil L. *tonsillae* the tonsils

torticollis L. *tortus* twisted + *collum* neck

torus L. swelling, knot, bulge

trabecula L. diminutive of *trabs* a beam

trachea Gr. rough, *tracheia* artery rough air-channel (see *artery*)

tragus Gr. *tragos* a goat (hairs here resemble a goat's beard)

trans- prefix L. through

trapezius Gr. *trapezion* a figure with four irregular sides

trapezoid Gr. *trapezion* + *-oid* like

triceps L. *tres* three + *caput* head
trigeminal L. *tres* three + *geminus* twin (i.e. three born together)
trigone L. *trigonum* from Gr. *trigonon* triangle, from *tres* three + *gonia* angle
triquetral L. *triquetrus* three-cornered
trochanter L. from Gr. a runner, from *trechein* to run
trochlea L. from Gr. *trochilia* a pulley
trophoblast Gr. *trophe* nutrition + *blastos* germ
tuber L. a protuberance, a knob
tubercle L. diminutive of *tuber*
tuberosity L. a big tuber
turbinate L. *turbo* a child's top
tympanum L. from Gr. *tympanon* a drum

U

ulna L. elbow
umbilicus L. the navel (Gr. *omphalos*)
umbo L. a boss, an elevation
uncinate L. *uncinatus* hooked
uncus L. a hook (Gr. *onkos* a barb)
urachus Gr. *ouron* urine + *echein* to hold
ureter L. from Gr. *oureter* urinary canal
urethra L. from Gr. *ourethra* urethra
uterus L. womb, belly (Gr. *hystera*)
utricle L. *utriculus* diminutive of *uter* a bag of hide (i.e. a small sac)
uveal L. *uvea* from *uva* grape
uvula L. a little grape, diminutive of *uva* a grape

V

vagina L. a sheath, a scabbard
vagus L. wandering
valgus L. bent outward
vallate L. *vallatus* surrounded with, from *vallum* a rampart

vallecula L. a little hollow, diminutive of *vallis* a valley
varicocele L. *varix* a dilated vein + Gr. *kele* tumour, hernia
vas L. a vessel, plural *vasa*
vas deferens L. *vas de* away from + *ferens* carrying, from *ferre* to carry, to bear
velum L. an awning, a veil
ventricle L. diminutive of *venter* the belly
vermiform L. *vermis* a worm + *forma* shape
vermis L. a worm
vertebra L. a joint, from *vertere* to turn
verumontanum L. *veru* a spit + *montanus* mountainous!
vesica L. a bladder, a sac
vesicle L. *vesicula* a little bladder, diminutive of *vesica*
vestibule L. *vestibulum* entrance chamber, anteroom
vibrissa L. *vibrare* to quiver
villus L. a tuft of hair
vincula L. a bond, a tie, form *vincire* to bind
visceral L. *visceralis*, from *viscus*
visceroptosis L. plural *viscera* organs + Gr. *ptosis* a falling
viscus L. an internal organ of a body cavity (Gr. *splanchnon*)
vital L. from *vita* life
vitelline L. *vitellus* yolk
vitreous L. *vitreus* glassy, from *vitrum* glass
vocal L. *vocalis* from *vox* voice (Gr. *phone*)
vomer L. a ploughshare
vorticose L. *vortex* a whirlpool, a whorl
valva L. a wrapper, from *volvere* to roll

X

xiphisternum Gr. *xiphos* a sword + *sternum* (q.v.)
xiphoid Gr. *xiphos* a sword + *-oid* like

Z

zonule Gr. *zone* a girdle
zygoma Gr. from *zygon* a yoke

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